IEA Heat Pumping Technologies Annex 47

Heat Pumps in District Heating and Cooling Systems

Task 1: Market and energy reduction potential

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Content

1. Introduction

The following report illustrates the current situation of the Austrian heat market as well as potential scenarios for future developments and discusses the potential role of large scale heat pumps in Austrian heat networks. The presented figures within this report are based on several recent studies on energy related topics in Austria of which two authors of this report where involved to a large extends. However, no additional quantifications have been performed for this report. For details on the methodologies on which the figures shown in this report are based the authors refer to the sources quoted in the report.

The report is structured as follows. Chapter 2 provides an overview of the current and future energy demand and supply situation in Austria and a detailed description of the heat demand in the Austrian building stock. This chapter is based on various recent studies and statistical data for Austria. In chapter 0 the potential for district heating grids in Austria is discussed. This section presents the main results of a study on potentials for efficient district heating and combined heat and power potentials by Büchele et al. (2015) which were conducted in the framework of the European Energy Efficiency Directive. The potential role of large scale heat pumps in future heat networks is discussed in chapter 0 based on basic consideration of economics within heat networks, the electricity market situation and available heat sources. Finally, chapter 5 deals with thermal storage options to support the integration of renewable energy sources (like heat pumps).

2. The energy situation now and for the future

This section provides an overview of the current energy demand and supply situation in Austria including the main challenges about the decarbonisation of the Austrian energy system in the future. The focus of this chapter is on energy demand for heating and cooling the Austrian building stock.

2.1. Overview of the main challenges in the country

The Austrian energy system is still heavily dependent on fossil fuels. The share of renewables in primary energy demand is currently below 30%. With an import share of 70% in total primary energy supply Austria also imports most fossil energy carriers.

Renewable shares vary between sectors. While Austria shows relatively high renewable shares (≈70%) in electricity production due to a high share of hydro (both run-of-river and storage) in the electricity mix, other sectors like transport are almost fully based on fossil fuels. Austria is committed to fulfil the Paris agreement which results in relatively ambitious CO_2 mitigation targets which would include significant transformations to reduce the use of fossil energy carriers.

In ambitious climate mitigation scenarios for Austria[1] (see Krutzler et al. (2015)) the use of fossil fuels is expected to decrease substantially. In an ambitious climate mitigation target primary energy use is expected to decrease with reductions of more than -40% until 2050 and fossil fuel use of only 218 TWh compared to 1 036 TWh in 2010.

The reduction of CO_2 emissions is a challenge for the whole energy systems. Some sectors in Austria are however easier to decarbonize than others. A study by Haas et al. (2017) shows that a transition towards a nearly fossil free electricity supply in Austria can be achieved by 2030 with acceptable costs of production by investing in additional wind parks, photovoltaic and electricity generation from biomass. Several studies (e.g. Kranzl et al. (2014), Müller (2010 and 2015)) also show that the heating and cooling supply of buildings in Austria can be decarbonized to a large extend until the year 2050 with a mix of decentral biomass based heating systems, increasing use of heat pumps and renewable district heating. One of the main open issues is the role of natural gas in heating and cooling which currently accounts for around 23% of final energy demand for heating and cooling in the building stock and has the highest market share of fossil heating systems in urban areas. A major challenge consists in decarbonising process heat supply within the industry sector which asks for much higher temperature levels. Currently those are delivered by coal and natural gas to a large extend.

The probably biggest challenge on the way to an almost carbon free energy supply in Austria is to decarbonise the transport sector which still relies to 90% on fuel oil. A mix of electrification, fuel cells based on hydrogen and various options of gas (including H_2, CH_4) driven vehicles in combination with increasing use of public transport could significantly reduce emissions from transport. However, the shares of those technologies are currently very low. Their uptake requires substantial investments in infrastructure and there is no clear strategy for a full decarbonisation of the Austrian transport sector.

The following section illustrates the total primary and final energy demand and supply mix for the year 2016 in Austria.

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[1] http://www.umweltbundesamt.at/umweltsituation/energie/energieszenarien/

2.2. Energy demand in Austria

Total primary energy demand in Austria in 2016 amounted to around 396 TWh.[2] Renewable energy sources accounted for less than 30% in total. 36% of primary energy is supplied by oil products, 21% by natural gas and around 9% is delivered by coal products. As local fossil resources are very limited, the primary energy supply in Austria is heavily dependent on imports. In 2016 around 70% of primary energy carriers were imports (mainly oil and natural gas). It should be noted however, that the use of fossil energy carriers has stagnated over the last decade while the use of renewables has increased. Table 1 and Figure 1 show the primary energy demand per energy carrier in Austria 2016.

Table 1: Primary energy demand per energy carrier in Austria 2016; Source: Energy balances Statistics Austria

Energy carrier	Primary energy demand 2016 [TWh]
Coal	36
Natural Gas	83
Oil	144
Renewables	117
Electricity Imports	7
Waste Combustion	9
Total	**396**

Figure 1: Primary energy per energy carrier 2016

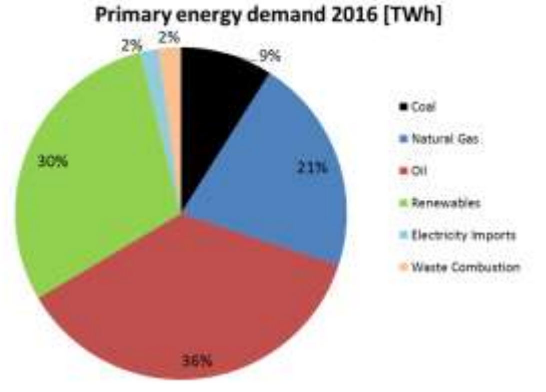
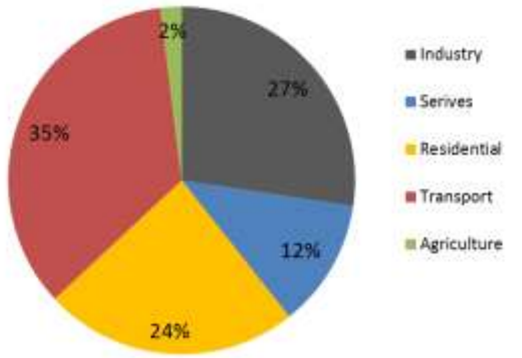


Table 2 and Figure 2 illustrate the final energy demand per sector in Austria. Final energy demand in Austria amounts to around 311 TWh annually. The transport sector accounts for around 35% of final energy demand (of which 90% are based on fossil fuels), industry makes up for 27%, households account for around 74 TWh (24%), the service sector for 37 TWh (12%) and the agricultural sector for around 6 TWh (2%).

Table 2: Final energy demand per sector in Austria 2016; Source: Energy balances Statistics Austria

Sector	Final energy demand 2016 [TWh]
Industry	85
Services	37
Residential	74
Transport	109
Agriculture	6
Total	**311**

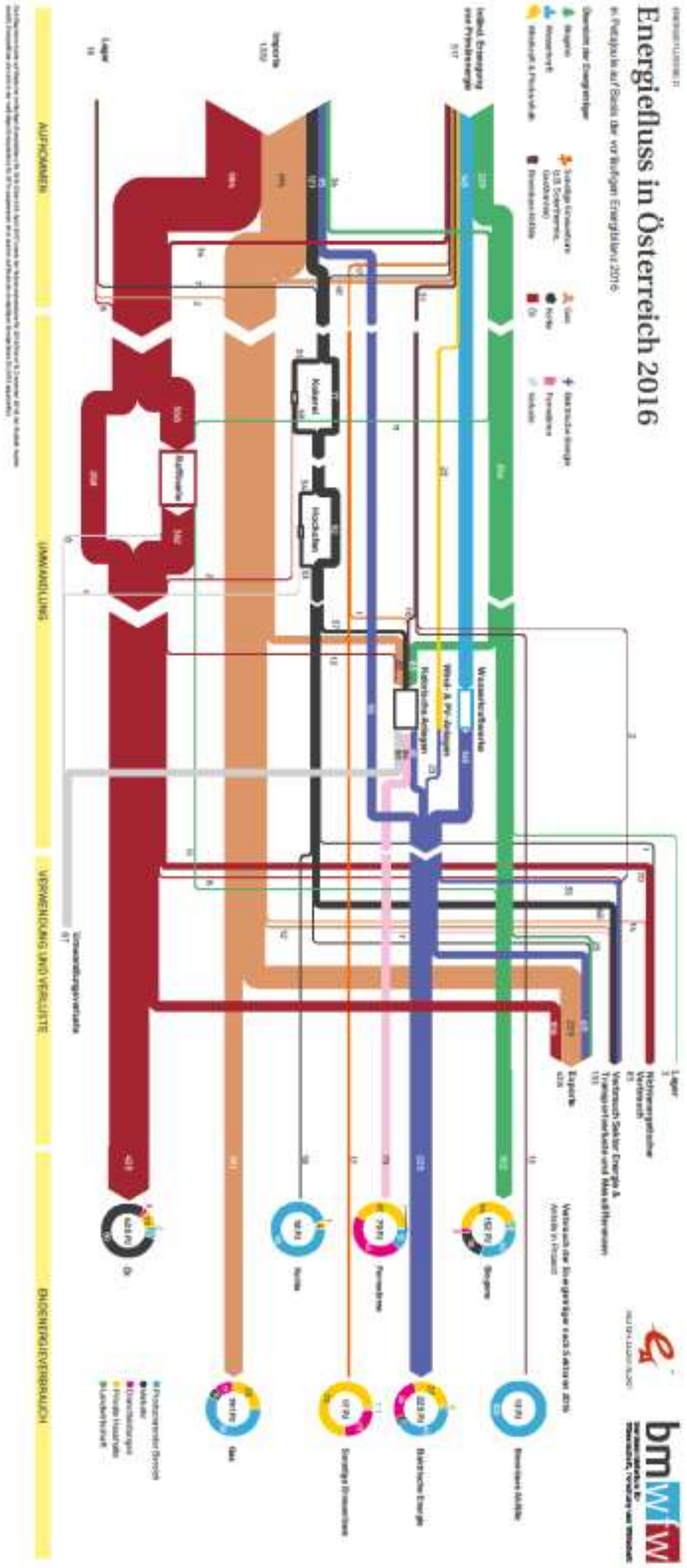
Figure 2: Final energy demand per sector 2016



The complete energy flow as a Sankey diagram can be seen in the following Figure 3 and the link provided in the caption of the figure.

[2] https://www.statistik.at/web_de/statistiken/energie_umwelt_innovation_mobilitaet/energie_und_umwelt/energie/energiebilanzen/index.html

Figure 3: Sankey diagram of energy flows in Austria; Source: https://www.bmwfw.gv.at/EnergieUndBergbau/Energieeffizienz/Documents/Energieflussbild%202017.pdf



2.3. Energy demand for heating and cooling

This section focuses on the energy demand for heating and cooling in Austria. Most of the figures presented in this section are derived from a study by Fleiter et al. (2016) on mapping heat supply in the European Union.[3] Final energy demand for heating and cooling across all sectors amounts to 169.5 TWh. Figure 4 shows shares of the end use categories "Space cooling, Process cooling, Space heating, Water heating, Process heating and Cooking". Space heating and process heating account for almost 89% of useful energy demand for heating and cooling in Austria. For the potential supply of heat pumps however the share of process heat is less relevant as a substantial part of process heat demand (mainly industries) exceed temperature levels suitable for the use of heat pumps. As the focus of this report is on the potential of large scale heat pumps in heat networks more detailed statistics are provided for heating and cooling the Austrian building stock. The final energy demand of the building stock (residential, service sector and space heating in industrial buildings) excluding process heating, process cooling and cooking amounts to around 96 TWh. Figure 5 shows the shares of end use categories in final energy demand for heating and cooling the Austrian building stock. It can be seen that space heating dominates with 87% of useful energy demand of those end use categories. Space cooling only accounts for a very small share of around 1%.

Figure 4: Shares of final energy demand for heating and cooling in Austria including process heating and cooling. Source: Fleiter et al. (2016)

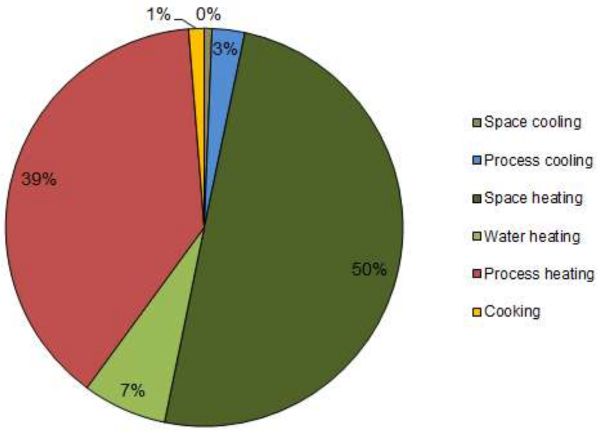


Figure 5: Final energy demand for heating and cooling in the building stock in Austria excluding process heating and cooling. Source: Fleiter et al. (2016)

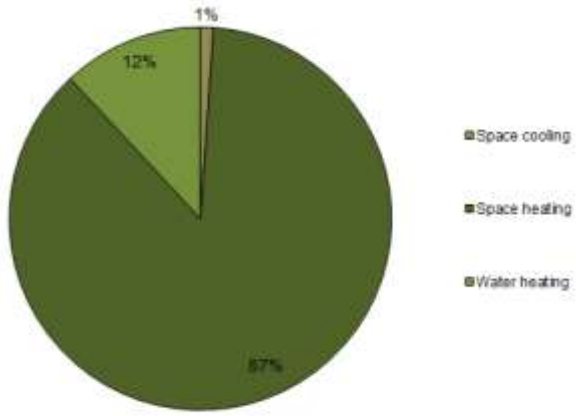


Table 3 shows the sector split of final energy demand per end use category and Figure 6 illustrates an additional breakdown of energy demand per sector into subsectors. With around 63.4 TWh residential buildings make up for the largest share in heating and cooling demand in Austria followed by the service sector with 19.5 TWh and heating and cooling demand in industrial buildings of 13.4 TWh.

[3] Detailed datasets are also available at: http://www.eeg.tuwien.ac.at/index.php?option=com_wrapper&view=wrapper&Itemid=86

Table 3: Final energy demand per end use category and sector in Austria 2012; Source: Fleiter et al. (2016)

	Residen-tial	Industry	Service	TOTAL	Residen-tial	Industry	Service	TOTAL
	Final energy demand [TWh]				Shares [-]			
Space heating	54.9	13.4	15.5	**83.8**	84.5%	16.4%	66.7%	**49.4%**
Hot water	8.5		3.2	**11.7**	13.1%	0.0%	13.6%	**6.9%**
Process heating			1.1	**67.2**	0.0%	0.0%	4.8%	**39.6%**
Process heating < 500°C		30.6			0.0%	37.6%	0.0%	**0.0%**
Process heating > 500°C		35.5			0.0%	43.7%	0.0%	**0.0%**
Cooking	1.5			**1.5**	2.4%	0.0%	0.0%	**0.9%**
Space cooling	0.1	0.0	0.8	**0.8**	0.1%	0.0%	3.3%	**0.5%**
Process cooling		1.8	2.7	**4.5**	0.0%	2.2%	11.5%	**2.7%**
TOTAL	65.0	81.2	23.3	**169.5**	100%	100%	100%	**100%**

Figure 6: Sector split of final energy demand in Austria; Source: Fleiter et al. (2016)

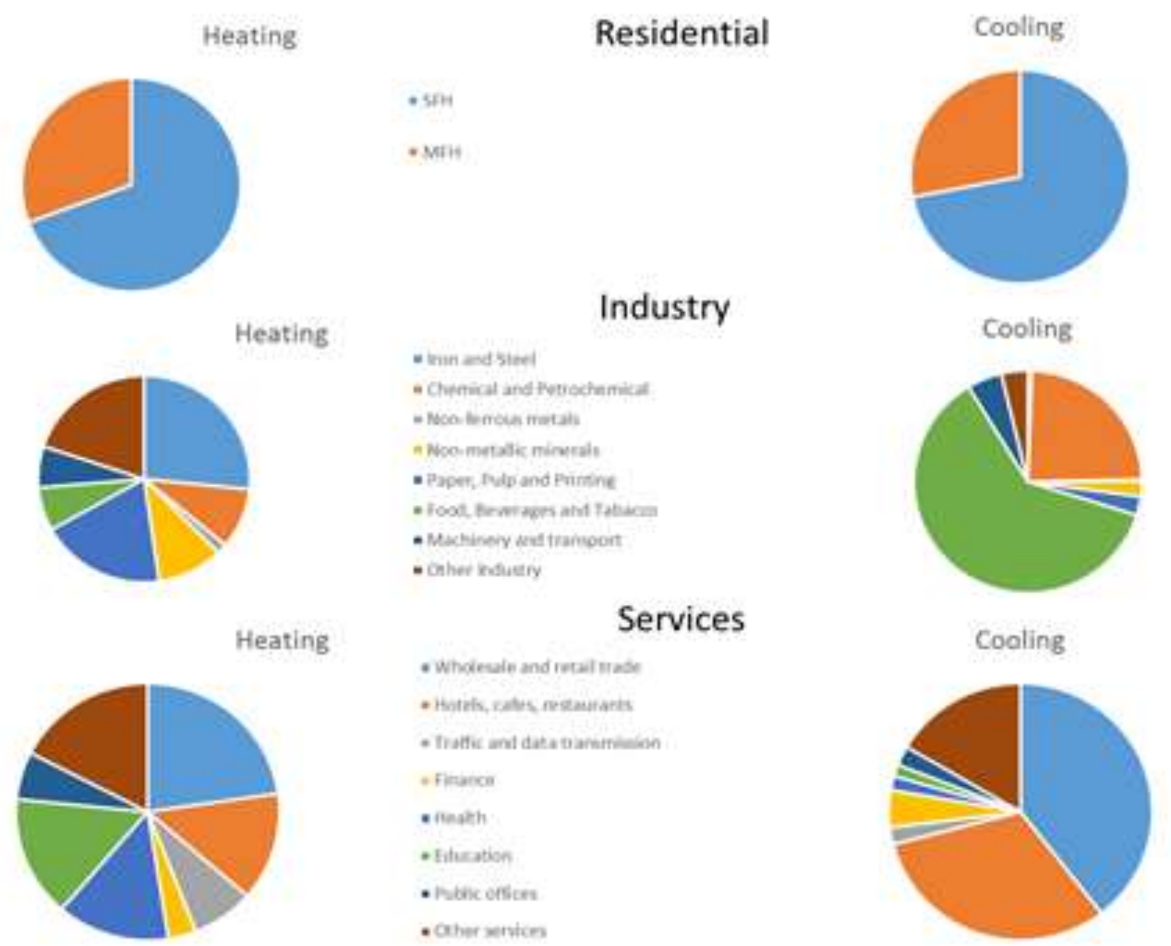
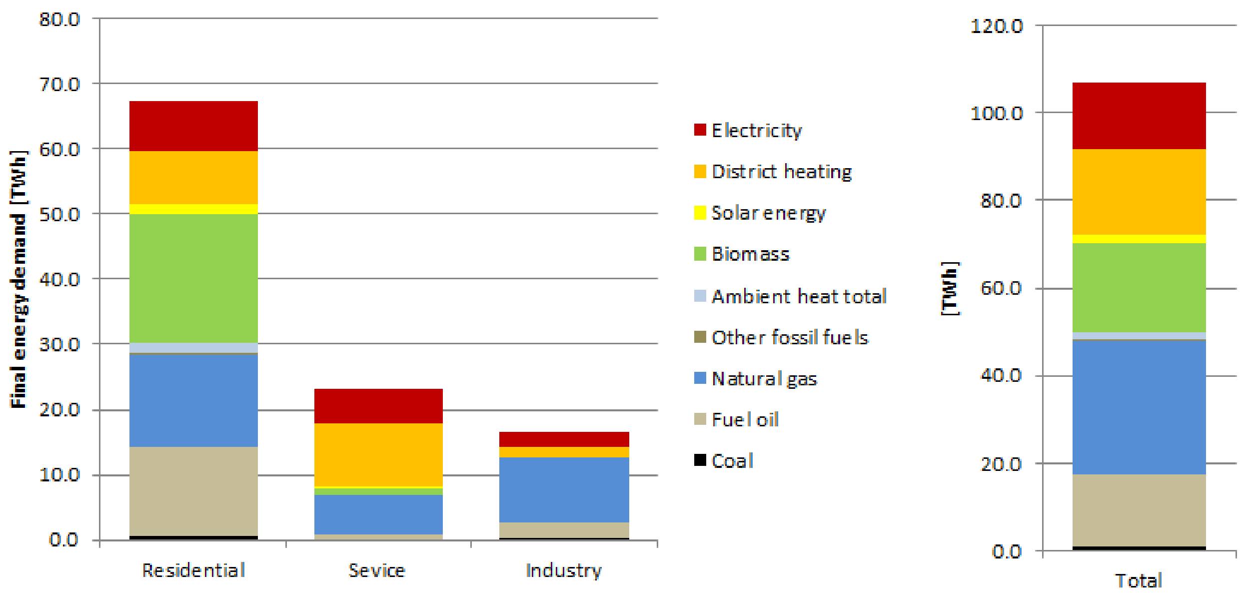


Figure 7 shows the energy carrier mix for heating and cooling in Austria (excluding process heating and cooling in the industry sector) for the year 2012. Fossil fuels account for roughly 45% of heating and cooling supply with natural gas consumption of 30.4 TWh (28.4%) and fuel oil as the main fossil energy carriers.

Renewables make up for 22.5% of supply. The main renewable energy carrier is biomass used for heating in the residential sector. The use of solar energy, geothermal and ambient heat only account for below 2%. The remaining energy demand for heating and cooling is provided by district heating (including heat generation from fossil fuels as well as renewable sources) and electricity (for direct electric heating, hot water supply and heat pumps). For the energy mix of electricity and district heating see section 2.6.

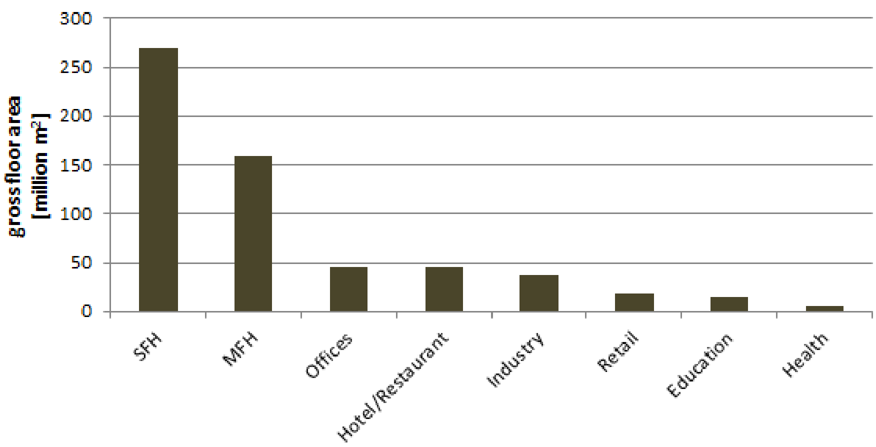
Figure 7: Energy carrier mix per sector in Austria 2012. Source: Fleiter et al. (2016)



2.4. Building stock characteristics and distribution of heat demand in Austria

In this section we provide a brief overview of the building stock characteristics in Austria and describe the spatial distribution of heat demand across Austria. The Austrian building stock amounts to a gross floor area of approximately 600 million m^2. Residential buildings account for more than 70%. The remaining area is split up among buildings attributed to service and industrial buildings as shown in Figure 8.

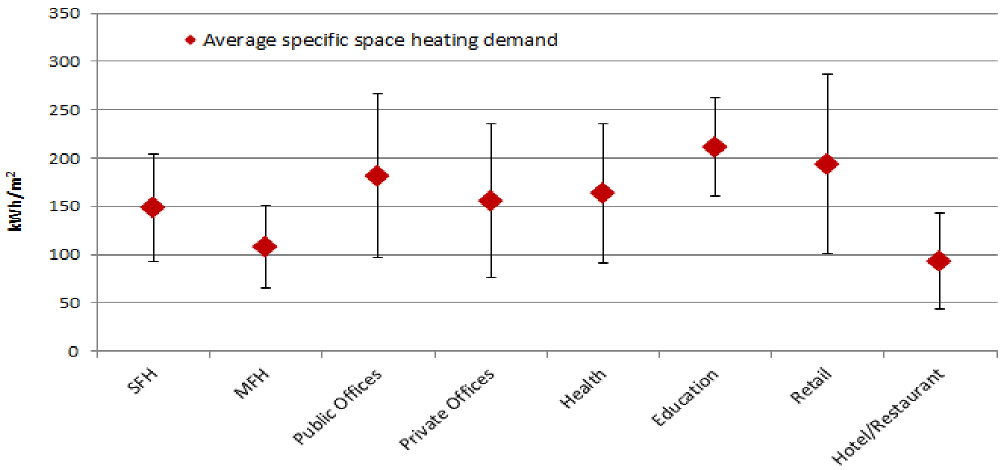
Figure 8: Gross floor area per building category in Austria; Source: database of model Invert/EE-Lab[4]



[4] www.invert.at

Figure 9 shows the average annual specific space heating demand and standard deviations per building category as error bars. Note that the actual demand in each building can deviate significantly from those calculated value due to user behaviour, occupancy and other factors.

Figure 9: Average and standard deviation of specific space heating demand per building category in Austria: Source: own calculations with model Invert/EE-Lab



The thermal quality of buildings in Austria heavily depends on the age of the building. Table 4 shows a breakdown of building and apartment units per construction period. It can be clearly seen that the building stock is dominated by relatively old buildings with more than 60% of existing buildings built before 1980. It can also be seen that a large share has not been renovated which results in a relatively high average specific heat demand of more than 150 kWh/m^2 in single family houses (SFH) and above 120 kWh/m^2 in multi-family houses (MFH). Average specific heat demand per construction period of residential buildings is shown in Figure 10. Residential buildings built after 1980 show specific heating demands below 100 kWh/m^2 in SFH and below 80 kWh/m^2 in MFH. This trend continues with currently built houses achieving much higher efficiency standards. However, their share in total heat demand of Austria is very low. Due to the long lifetime of buildings and relatively low renovation rates (around 1% p.a.) heating needs will be dominated by a rather old building stock even for time horizons of more than 30 years which highlights the importance of thermal refurbishment to reduce energy needs of the building stock. It is estimated that reaching ambitious climate mitigation targets would require renovation rates in the range of 2% to 3% and most of renovation activities would have to lead to rather high thermal standards beyond the typical renovation standards currently applied.

With respect to district heating it should also be noted that the age of the Austrian building stock (including historical buildings) is a major barrier to bring down the temperature levels of heating grids which would significantly benefit the use of large scale heat pumps in existing heat networks.

Table 4: Buildings per construction period in Austria; Source: Statistic Austria

	1000 buildings	share	1000 housing units	share
Residential buildings, pre-1945, unrenovated [1)]	228	12%	523	15%
Residential buildings, pre-1945, renovated [2)]	146	8%	336	9%
Residential buildings, 1945–1980, unrenovated [1)]	448	24%	921	26%
Residential buildings, 1945–1980, renovated [2)]	307	16%	648	18%
Residential buildings, 1981–2000, unrenovated	492	26%	928	26%
Residential buildings, 2001–2020, unrenovated	112	6%	208	6%
Non-residential service buildings, pre-2010	145	8%		

1) unrenovated: no measures implemented in the building shell after 1994

2) renovated: measures implemented (including non-thermal measures) since 1995

Figure 10: Average specific heat demand per construction period for single family (SFH) and multi-family buildings (MFH) in Austria; Source: Own calculations in model Invert/EE-Lab

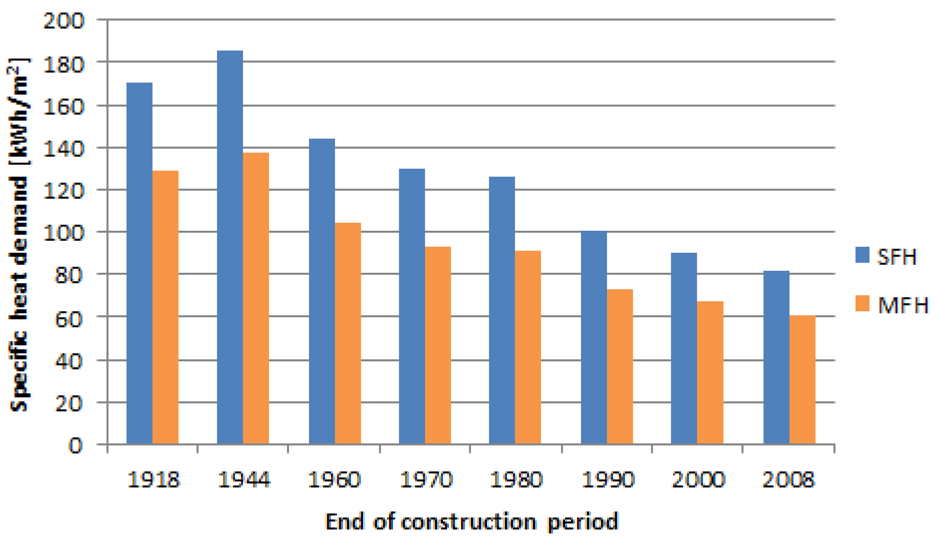


Table 5 and Figure 11 show a breakdown of useful energy demand for heating and cooling in the residential sector for SFHs and MFHs in urban and non-urban regions. SFH make up for around 70% of total heat demand. A major share of those single-family houses is located in non-urban regions. Multi-family houses are located in urban and non-urban regions. Note that also relatively small municipalities in Austria can have a dense centre and include settlements with multi-family houses.

Table 5: Useful energy demand for H&C residential; Source: Fleiter et al. (2016)

	Heating and cooling [TWh]
SFH	46.1
MFH	18.8
Urban, SFH	3.9
Urban, MFH	11.2
Non-Urban, SFH	42.2
Non-Urban, MFH	7.6
TOTAL	65.0

Figure 11: Useful energy demand for H&C residential; Source: Fleiter et al. (2016)

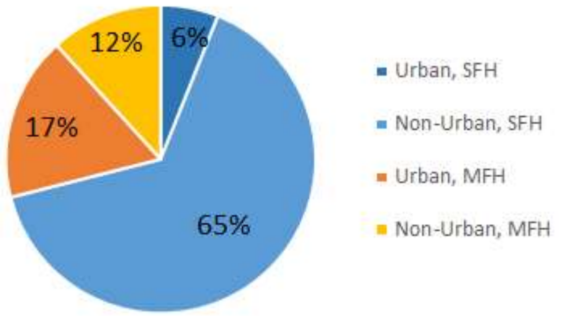
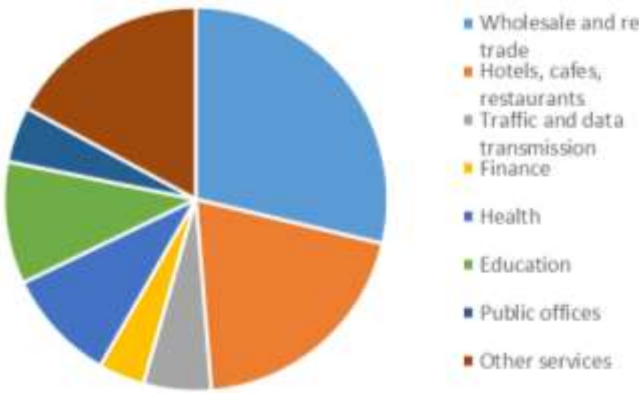


Table 6 and Figure 12 show useful energy demand for heating and cooling (including process cooling) of the service sector. While cooling needs are still very low in the residential sector, cooling accounts for a relatively large share in the service sector. Most of the cooling demand however can be attributed to process cooling (11.5% of final energy demand, see Table 3). Space cooling only accounts for 3.3% of total final energy demand in the service sector (see Table 3). Note that the shares of cooling needs in final energy demand are lower because cooling systems typically operate with energy efficiency rating (EER) >2.5 while heating systems based on combustion operate at conversion efficiencies below 1.

Table 6: Useful energy demand for H&C in the service sector; Source: Fleiter et al. (2016)

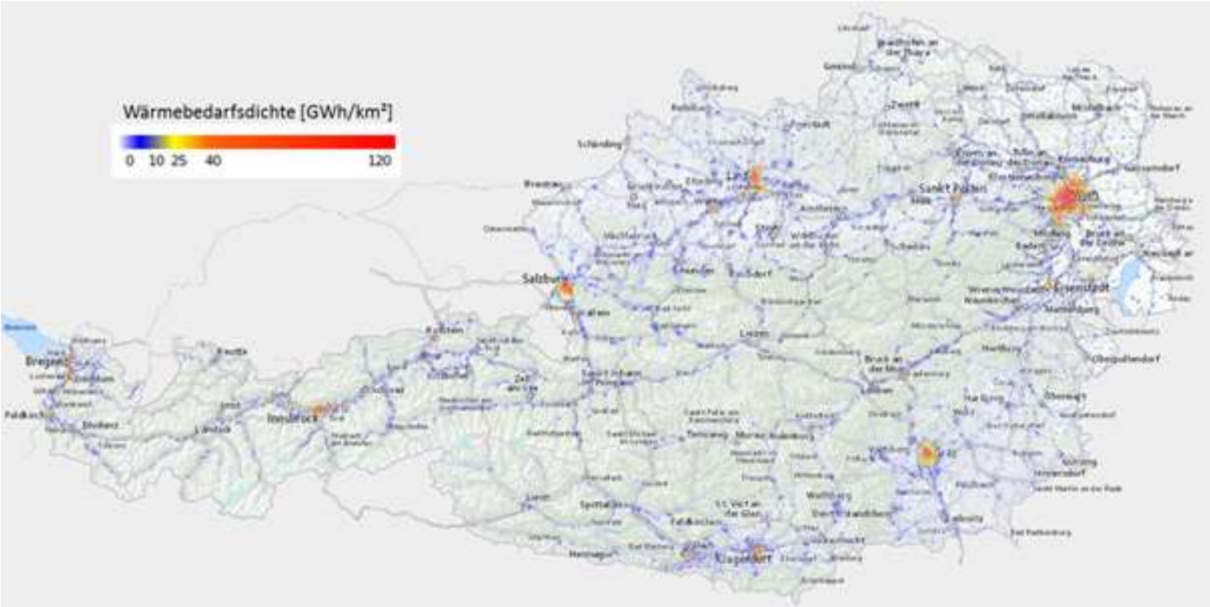
	H&C	Heating	Cooling
Wholesale and retail trade	6.9	3.5	3.4
Hotels, cafes, restaurants	4.8	2.1	2.7
Traffic and data transmission	1.4	1.2	0.2
Finance	0.9	0.5	0.4
Health	2.3	2.1	0.2
Education	2.5	2.3	0.1
Public offices	1.1	0.9	0.2
Other services	4.1	2.7	1.4
TOTAL	**23.9**	**15.4**	**8.6**

Figure 12: Useful energy demand for H&C in the service sector; Source: Fleiter et al. (2016)



Studies by Müller et al. (2014) and Buechele et al. (2015) aim at the identification of the technical potential for district heating in Austria, heat demand was spatially disaggregated to a spatial resolution of 100 m x 100 m. Figure 13 shows the results of the analysis as a heat density map which is available at www.austrian-heatmap.gv.at.

Figure 13: Distribution of heat demand in Austria; Source: www.austrian-heatmap.gv.at



The distribution of total heat demand calculated for the year 2012 over six density classes (ranging from less than 6 GWh/km² to over 60 GWh/km²) can be seen in Figure 14. The model results reveal that 10% of heat demand can be allocated to areas with heat demand densities of below 10 GWh/km², the largest share of 62% to areas with heat densities between 10 and 35 GWh/km² and the remaining 28% to areas with high heat demand densities of over 35 GWh/km².

Figure 14: Heat demand per heat density class in Austria; Source: Büchele et al. (2015)

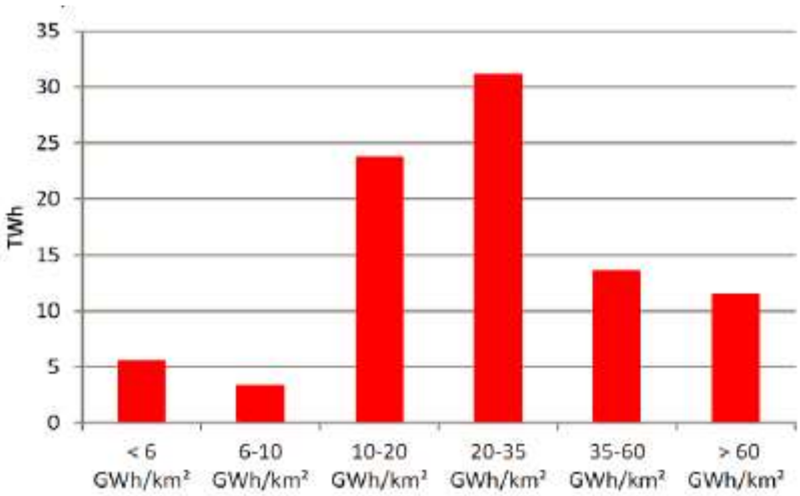
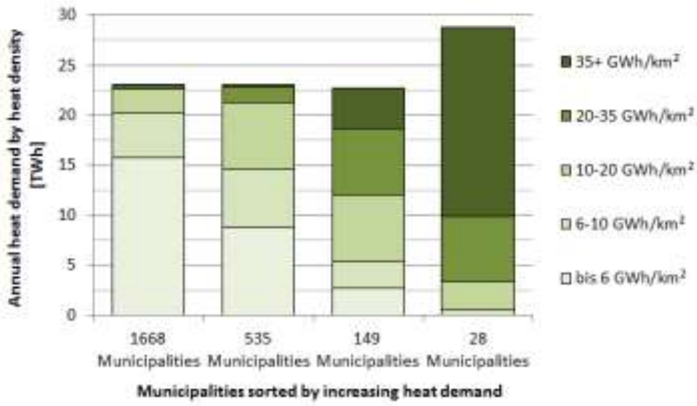


Figure 15 illustrates the heat demand sorted by the total heat demand of municipalities in Austria split up in heat densities within those municipalities. It can be seen that the majority of municipalities consists of areas with relatively low heat densities. Heat densities above 20 GWh/km^2 are only observed in town centres and only amount to several GWh of annual heat demand. District heating in those areas is restricted to very small networks with thermal power ratings below 1 MW which are typically less competitive compared to decentral heating options. However, as shown in this report heat networks based on biomass also exist in those regions. Figure 15 also reveals that higher density areas above 35 GWh/km^2 are only located in a rather small number of municipalities which represent the main urban regions in Austria. Note that 23 of the 28 municipalities shown in the bar with the highest heat densities are the districts of the capital Vienna. The relation of the spatial distribution of heat demand in Austria and potentials for district heating will be further discussed in chapter 0 of this report.

Figure 15: Heat demand in Austrian municipalities; Source: Büchele et al. (2015)



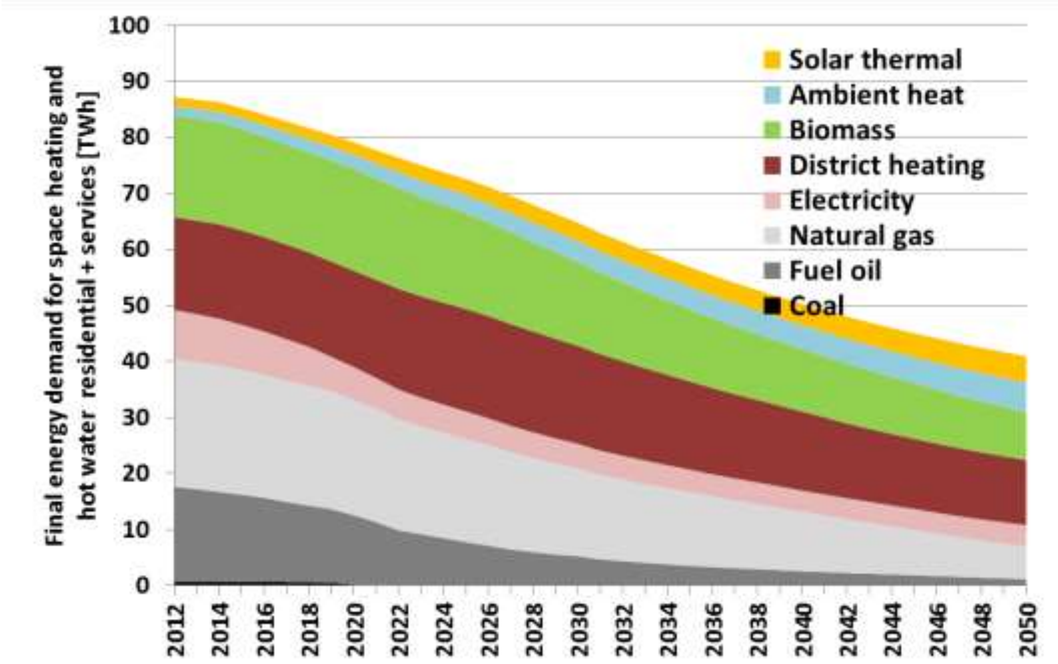
2.5. Development of heat demand and main energy carriers

Several scenarios for the development of heating and cooling demand have been calculated in various projects. (e.g. Müller (2015), Büchele et al. (2015), Kranzl et al. (2014), Fleiter et al. (2016), Krutzler et al. (2015)). Within this report a brief overview of the main trends expected for a time horizon until 2050 is given.

In all scenarios space heating demand is expected to decrease substantially while hot water demand is expected to be more or less stable across the simulation periods. Total final energy demand for heating is expected to decrease up to -50% until 2050. While space cooling demand is expected to increase significantly, it is expected to still only account for a small share (<5%) of final energy demand for heating and cooling the Austrian building stock.

Figure 16 illustrates an exemplary scenario for the development of final energy demand for space heating and hot water in Austria assuming ambitious policy measures to reduce emissions and increase the shares of renewable energy sources. The analysis shows that with ambitious thermal refurbishment measures the energy demand of the Austrian building stock and resulting CO_2 emissions could be drastically reduced. While it is expected that fuel oil could almost vanish from the energy supply mix, natural gas is expected to still account for a relatively large share of heat supply until 2050. It should be noted that due to increasing thermal efficiencies of the building stock also heat densities in urban areas decrease. However, it is expected that there will still be a substantial potential for district heating (which is only economically feasible for relatively high heat densities areas) due to further urbanization (e.g. see Müller et.al. (2014), Büchele et.al (2015)).

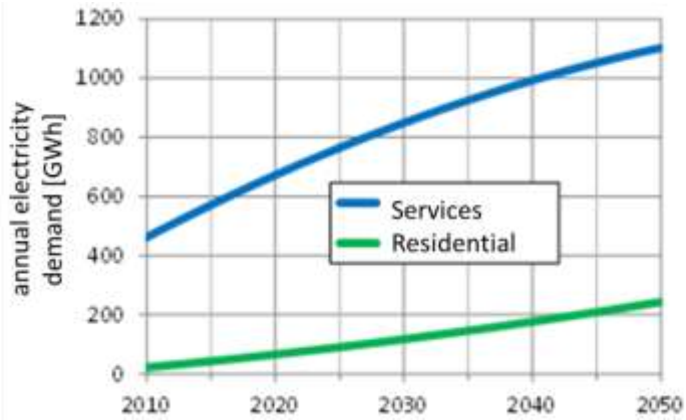
Figure 16: Exemplary scenario for the development of heat demand in Austria until 2050; Source: Own calculations with Invert/EE-Lab



The projections for heat demand developments highly depend on the expected regulatory measures and policies related to energy use and efficiency in buildings. In a recent study Müller et al. (2017) estimate the final energy demand for space heating and hot water to decrease to around 70 TWh in 2030 and 55 TWh in 2050 assuming existing policy measures to be in place until 2050. In a scenario assuming several ambitious policies to increase the efficiency of the building stock a further reduction to 65 TWh in 2030 and 45 TWh 2050 is estimated. This would correspond to a reduction of more than -45% compared to current levels of final energy demand for heating. In such a scenario renovation rates would have to increase from 1%-1.5% to around 3%-3.5% in the time period until 2050.

In most scenario calculations cooling demand of the Austrian building stock is expected to increase. In the Fleiter et al. (2012) space cooling demand is estimated to increase for 0.8 TWh in 2012 to around 1.5 TWh in 2030. Müller et al. (2017) estimate space cooling demand for residential buildings and the service sector to increase from 0.5 TWh in 2012 to 1.4 TWh in 2050 (see Figure 17). Although there is high uncertainty about the magnitude of the increase, all scenarios show a significant increase in cooling demand in Austria.

Figure 17: Scenario for the development of electricity demand for space cooling in Austria; Source: Müller et al. (2017)



The development of gas demand for heating and cooling including process heating in the industry sector was also estimated in Fleiter et al. (2016). Despite the significant decrease in space heating demand the consumption of natural gas is estimated to be less affected. For 2012 natural gas demand for heating (including space heating, process heating and hot water) is estimated to be 52 TWh. It is expected to decrease to around 48 TWh by 2030 mainly due to reductions of gas demand in the residential sector. In the long term also gas demand in the building sector is expected to decrease significantly which is considered to be a prerequisite for achieving emission reductions in line with emission reduction targets of more than -80% in Austria until 2050. In the ambitious scenario in Müller et al. (2017) natural gas demand for space heating and domestic hot water is reduced from around 22 TWh in 2015 to around 6 TWh in 2050. In scenarios by Krutzler et al. (2015) total primary energy demand for natural gas (including transport and electricity) is estimated to be relatively stable until 2030. For the year 2050 natural gas demand also decreases significantly at least for ambitious emission reduction targets (WAM+ scenario).

In the ambitious policy scenario Krutzler et. al (2015) estimate electricity demand in Austria to increase from 61.5 TWh in 2010 to 64.4 TWh until 2030. For 2050 a slight decrease compared to the base year is calculated which is mainly an effect of successful efficiency measures leading to overall reductions in final energy demand in this scenario. Given the potential role of electricity in transport (e-mobility and H_2 generation) and in some main industrial process (e.g. steel production) and to a smaller extend power to heat in buildings and district heat networks, electricity demand in Austria could also substantially increase even in ambitious climate reduction scenarios.

Whether those ambitious efficiency and renewable energy potentials will also depend on the existing and future energy infrastructure in particular electricity and gas grids as well as district heat networks and the existing energy supply technologies. The current situation in Austria will be presented in the following section.

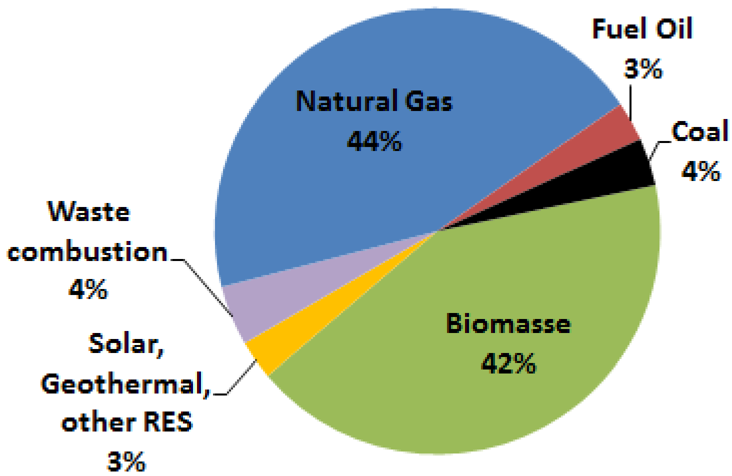
2.6. Energy Infrastructure in the country

In this section an overview of the existing energy related infrastructure in Austria is given. Section 2.6.1 illustrates existing heating and cooling networks in Austria while section 2.6.2 and 2.6.3 briefly introduce the supply infrastructure for electricity and natural gas.

2.6.1. District Heating Networks

This section is based on a study by Buechele et al. (2015) on the potential of district heating and cogeneration in Austria. According to the energy balance provided by Statistics Austria[5] the district heating sector in Austria has grown significantly since the 1970s. Between 2000 and 2015 district heat production in Austria rose by 75% with a first peak in 2010, due to a particularly cold winter with 13% more heating degree days compared to the long-term average, and a following warm winter in 2011, with 12% fewer heating degree days than the long-term average. Then after 2010 the district heating demand more or less stagnated. The supplied district heat of 21 TWh covered nearly 20% of total heat demand of the household and service sector. In the industrial sector this share accounts for only 5% and in the agricultural sector for less than 4%. The main energy carriers used to supply heat in heat networks are natural gas (44%) and biomass (42%). The remaining heat is supplied by waste combustion, fuel oil and coal. Other renewables (solar thermal, geothermal and others) only account for around 3% of heat supply in Austrian heat networks (see Figure 18).

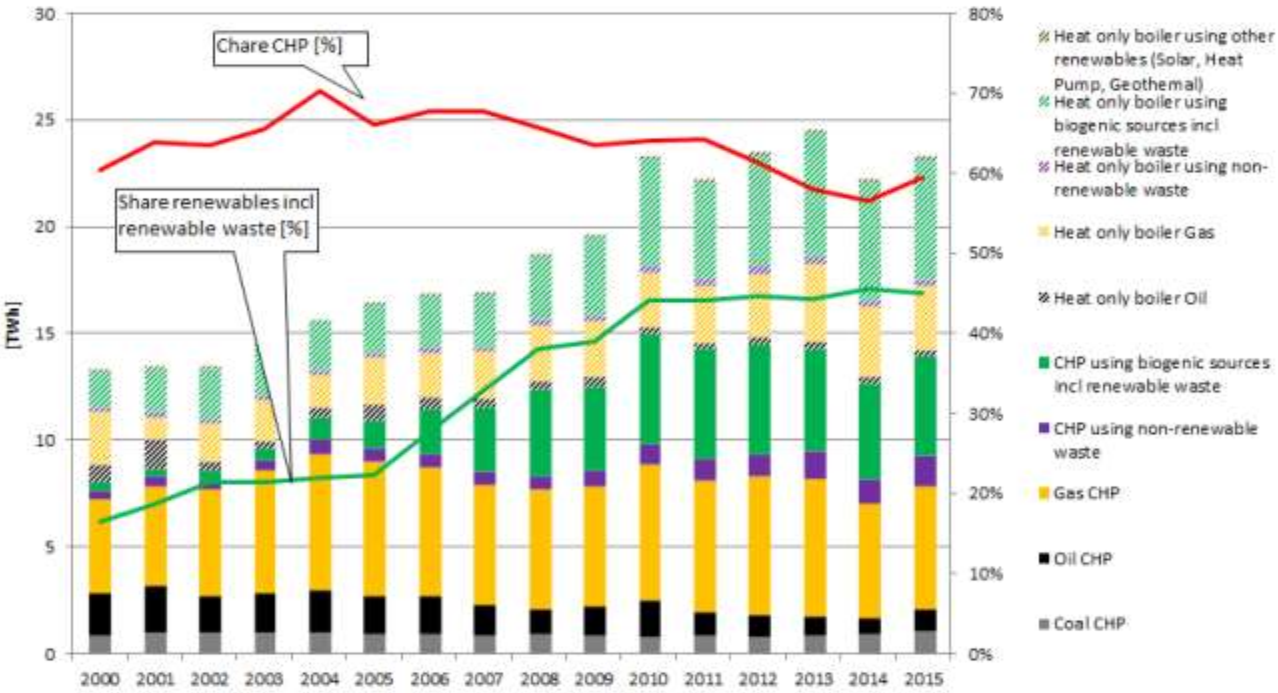
Figure 18: Energy carrier mix in Austrian heat networks 2012; Source: Buechele et al. (2015)



The district heat generation distinguished between combined heat and power (CHP) plants and heat only boilers by energy carriers is shown in. Whereas the district heating production from fossil fuels (coal, oil and gas) stayed relatively constant from 2000 to 2012 the additional demand in this period was mainly generated from renewable energy sources. The total share of renewable energy sources in district heat generation increased from 16% in 2000 to 45% in 2012. During this period, the share of heat generated in CHP plants remained between 60% and 70%.

[5]https://www.statistik.at/web_de/statistiken/energie_umwelt_innovation_mobilitaet/energie_und_umwelt/energie/energiebilanzen/index.html

Figure 19: Development of Energy carrier mix and share of cogeneration in Austrian heat networks; Source: Buechele et al. (2015)



In 2012 80% of the installed capacity of the 83 fossil fuelled plants and 76% of the installed capacity of the almost 500 biogenically fuelled pants were CHP plants. The total heat capacity of all CHP plants (fossil and biogenic) added up to more than 9.2 GW_{th} in 2012, generating almost 15 TWh of heat.

In Austria, large fossil-fuel-powered heat only plants are almost exclusively found in large cities. The majority of heat only plants are smaller plants using biogenic energy sources. According to the 2013 biomass heating survey (Haneder and Furtner (2014)) more than 1 140 wood-chip-fired furnaces with a thermal power of more than 1 MW_{th} have been installed since 1980, adding up to a total capacity of almost 3 000 MW_{th}.

Other heat sources for district heating are waste incineration plants and industrial excess heat. In Austria there are 32 incineration and co-incineration plants with a capacity of more than 2 t/h of waste in operation. 15 of these are industrial plants, 8 are operated by energy providers and 9 by municipal or recycling companies (Grech and Stoiber (2014)). Plants operated by municipalities and energy providers mainly feed heat into district heating grids whereas industrial (co-)incineration plants are usually used to generate heat for internal processes.

Additionally, several industrial sites feed excess heat into district heating networks and provide baseload heat. Below examples of waste heat being fed into district heating grids in Austria are listed:

- The CHP plant of OMV Schwechat supplies the district heating grid in Vienna.
- Hrachowina and Henkel Austria supply the district heating grid in Vienna.
- The Marienhütte steelworks supplies the district heating grid in Graz.
- Böhler Edelstahl supplies the district heating grid in Kapfenberg.
- Voestalpine Stahl Donawitz supplies the district heating grid in Leoben.

- The Hofmann Kirchdorf cement works supplies the district heating grid of EnergieAG in Kirchdorf.
- The Schweighofer Hallein paper factory supplies the district heating grid in Salzburg.

Other renewable heat sources for district heating (geothermal energy and larger-scale solar thermal plants) are only installed in a small number of heating grids so far. Geothermal heat is currently used in 15 heating grids in Austria. Total installed heat capacity amounts to around 93 MW_{th}, generating an annual thermal output of around 139 GWh/a (see Stanzer et al. (2010)). Large-scale solar thermal plants are used to feed solar heat into district heating grids. At the end of 2016, more than 35 thousand square metres of large-scale (>1 000 m² collector area) solar thermal panels were in operation in Austria summing up to a thermal capacity of almost 25 MW_{th}. Table 7 lists a selection of solar thermal plants in Austrian heat networks.

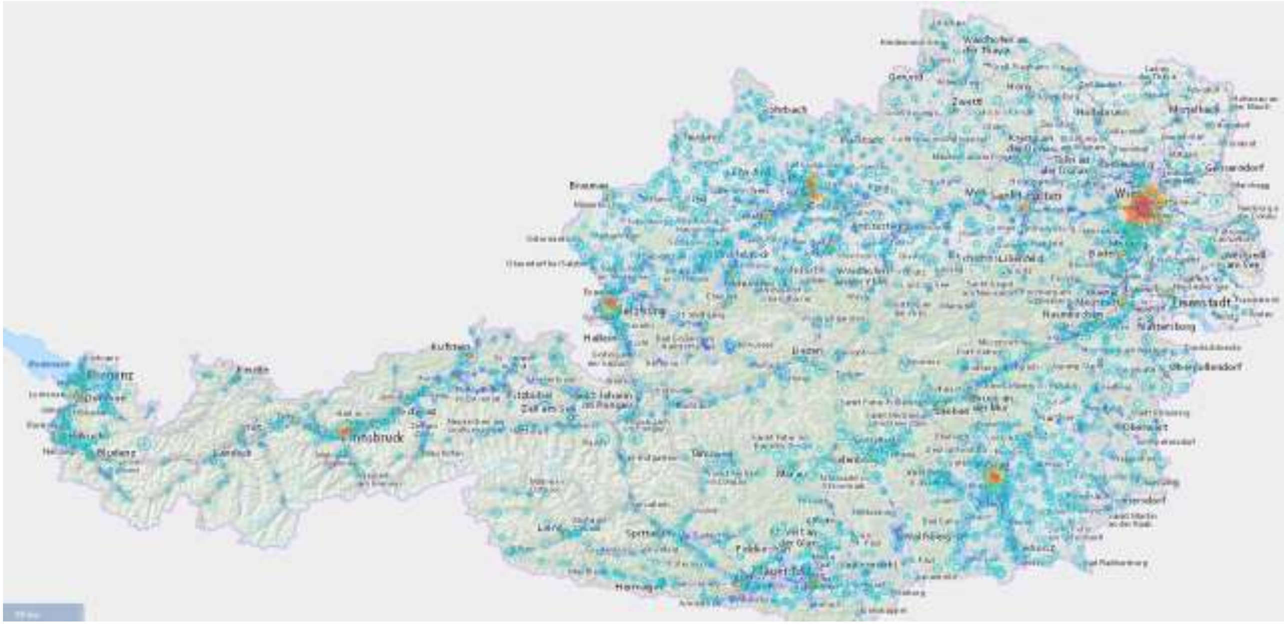
Table 7: Solar thermal systems in Austrian heat networks; Source: Büchele et al. (2015)

Name of project/location	Year	Operator	Location	Collector area [m²]	Capacity [kW_{th}]
Fernheizwerk/AEVG	2006–ext.2014	solar.nahwaerme.at, AT	Graz	7 750	5 300
Wasserwerk Andritz	2009	solar.nahwaerme.at, AT	Graz	3 860	2 702
Wels	2011	Wels Fernwärme, AT	Wels	3 388	2 400
Berliner Ring	2004	solar.nahwaerme.at, AT	Graz	2 480	1 736
Eibiswald	1997	Nahwärmegen. Eibiswald, AT	Eibiswald	2 450	1 715
Salzburg	2011	GSWB	Salzburg	2 150	1 505
Waldmühle Rodaun	2015	Wien Energie	Kaltenleutgeben	1 500	1 050
Perg	2014	HABAU, AT	Perg	1 420	1 000
UPC Arena	2002	nahwaerme.at, AT	Graz	1 407	985
Loeben	2013	Brauerei Göss	Loeben	1 375	963
Gleinstätten	2006	Nahwärme Gleinstätten GmbH,AT	Gleinstätten	1 315	921
Bilderland	1979	Bilderland GmbH, AT	Bilderland	1 284	899
Bad Mitterndorf	1997	Genossensch. Biosolar BM, AT	Bad Mitterndorf	1 120	784
Innsbruck	1999	Wohnen am Lohbach I, AT	Innsbruck	1 080	756
Sieghartskirchen	2013	Fleischwaren Berger G.m.b.H.	Sieghartskirchen	1 068	748
Bolaring	2000	Gem. Salzburger Wohn.m.b.H., AT	Salzburg	1 056	739
Innsbruck	2009	Lodenareal, AT	Innsbruck	1 050	735

Characteristics of heating grids in Austria

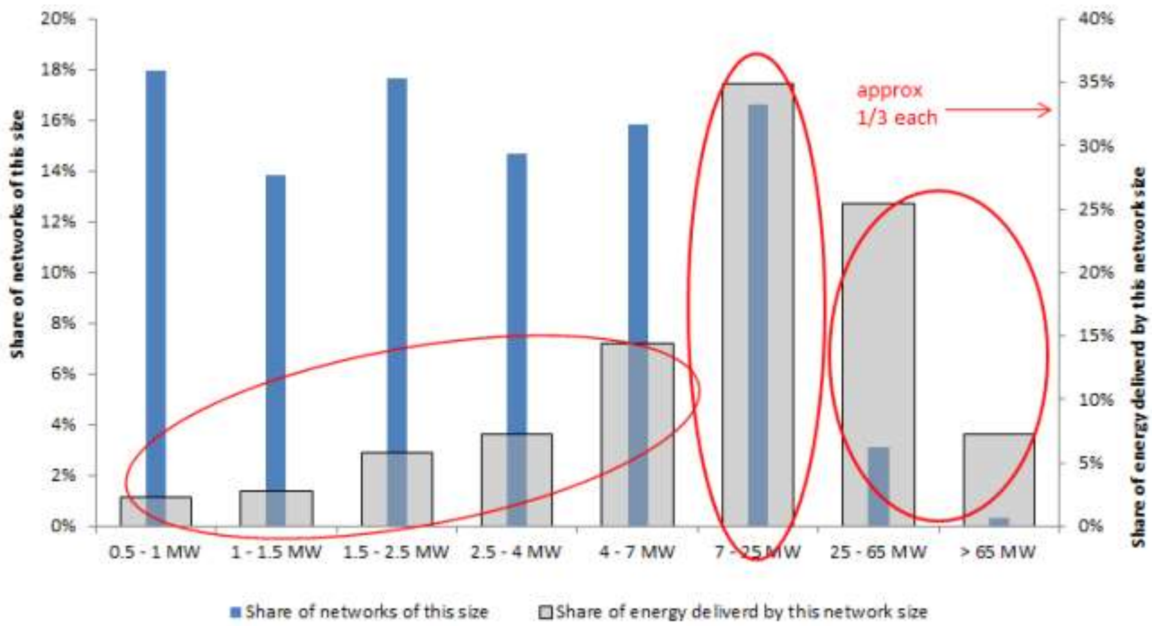
Figure 20 illustrates the wide geographical coverage of heat networks in Austria. More than 1 600 district heating networks are operated in Austria according to the Austrian heatmap.

Figure 20: Locations of heat networks in Austrian. Source: www.austrian-heatmap.gv.at



On the basis of a dataset from the "qm-Heizwerke" database (quality management for heat plants and networks in Austria) on connected loads and sales volumes of 169 biomass grids it was possible to estimate the connected load and average full load hours for biomass networks in different size classes. Figure 21 shows the results of this estimation. Heat networks with connected loads up to 25 MW account for approximately 14% to 18% of the networks, less than 4% of biomass networks have connected loads over 25 MW, and less than 1% show connected loads over 65 MW. The five network sizes up to 7 MW altogether account for ⅓ of the delivered heat, ⅓ of heat supply is delivered in networks between 7 MW to 25 MW and ⅓ in networks over 25 MW.

Figure 21: Heat network characteristics in Austria; Source: Büchele et al. (2015), data source: qm Heizwerke database



A further analysis of the qm database was conducted taking into account additional parameters. On the basis of a complete dataset of 122 local biomass district heating grids the following three cluster were identified:

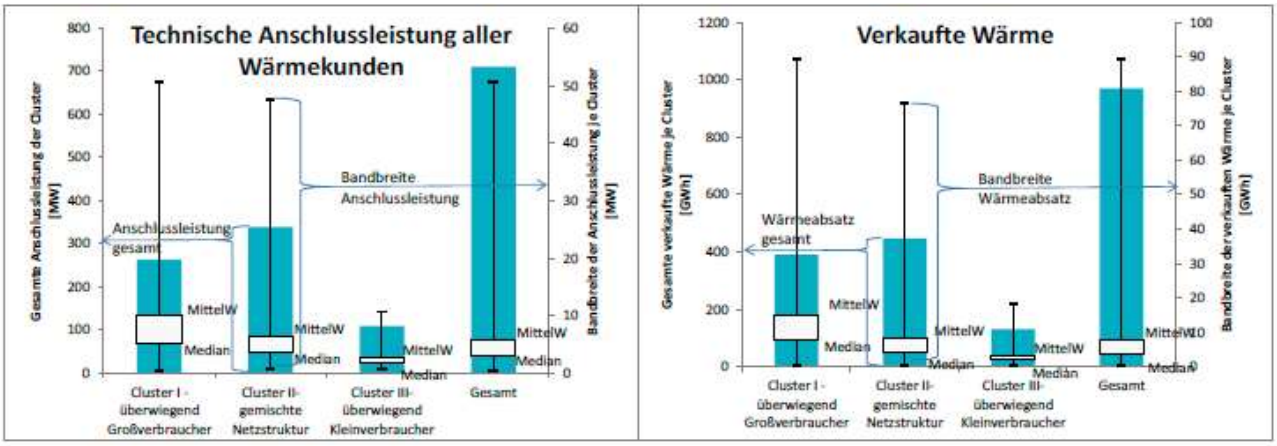
- Cluster I, primarily bulk consumers: more than 75% of the heat sold goes to customers with a heating consumption volume of over 150 000 kWh/a.
- Cluster II, mixed consumer structure: less than or equal to 75% of the heat sold goes to customers consuming more than 150 000 kWh/a and less than or a maximum of 25% of the heat sold goes to customers consuming less than 50 000 kWh/a.
- Cluster III, primarily small consumers: less than 75% of the heat sold goes to customers consuming more than 150 000 kWh/a and more than 25% of the heat sold goes to customers consuming less than 50 000 kWh/a.

For these network cluster following parameters were analysed to find minimum, maximum, mean and median values:

- number of heating grids per cluster
- number of consumers (= heat customers)
- total line length
- technical rated output for all heat customers
- network loss capacity
- energy supply: generated heat (= fed into the grid)
- heat distribution, annual sales
- network losses as a percentage of supplied heat
- heat density
- number of boilers, their capacities and energy source used per heating grid

21% of the analysed networks were allocated to Cluster I (mainly bulk consumers), 44% to Cluster II (mixed consumer structure) and the remaining 34% to Cluster III (mainly small consumers). Looking at the number of customers within each cluster, the number decreases for grids with mainly bulk consumers but in the analysed grids the majority of customers are not in the cluster with only small consumers but in the cluster with a mixed structure. The connected load and sold heat increase for networks with primarily bulk consumers, which gives them an economic advantage. For example, 40% of annual heat is sold in Cluster I although it only accounts for 18% of consumers, whereas only 14% of the heat is sold in Cluster III accounting for over 34% of customers. Figure 22 illustrates these parameters.

Figure 22: Characteristic of biomass based heat networks in Austria; Source: Büchele et Aal. (2015), data source: qm Heizwerke database



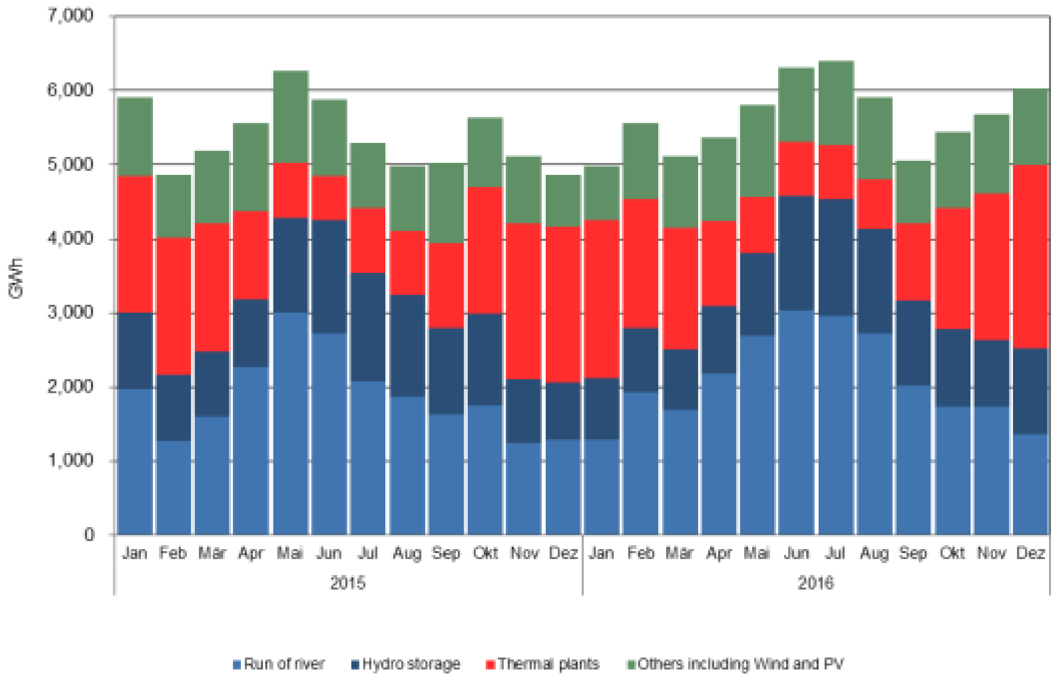
Heat generators installed in the 122 biomass grids were also analysed. 98% of the grids have a biomass boiler and 8% have a biomass CHP facility. 55% of the grids have an oil- or gas-powered peak load boiler, and 29% of grids obtain some of their heat from heat recovery systems (HRS). Other generation technologies such as external boilers, waste heat from industry or biogas facilities can be found in 10% of the grids. Typically, the biomass boilers have a capacity of between 0.5 MW and 10 MW, with 50% of boilers capacities below 1.6 MW. Typical oil-/gas-fired peak load boilers have an installed capacity of between 0.5 MW and 25 MW, with 50% of the capacities below 3 MW.

2.6.2. Electricity supply infrastructure

The Austrian electricity supply is characterised by a high share of generation from renewable energy sources.

Figure 23 shows domestic electricity generation in Austria. The figure reveals the high shares of hydro generation both from run-of-river and hydro storage plants in Austria. Depending on the weather in a year, generation from hydro plants account for around 50% to 60% of electricity consumption in Austria. Generation from other renewables (wind, photovoltaic, geothermal plants and biomass) accounted for around 17% of total consumption. Electricity generation from wind turbines is increasing rapidly and is concentrated to a rather small area in the east of Austria. In recent years Austria has been a net importer of electricity. In 2016 net imports accounted for around 7 TWh which is almost 10% of the gross inland electricity consumption of 70.2 TWh (excluding electricity for pumping in hydro storage plants). The majority of imports can be allocated to electricity exports from Germany to Austria.

Figure 23: Electricity generation in Austria 2015 and 2016, Source: https://www.e-control.at/statistik/strom/betriebsstatistik/betriebsstatistik2016

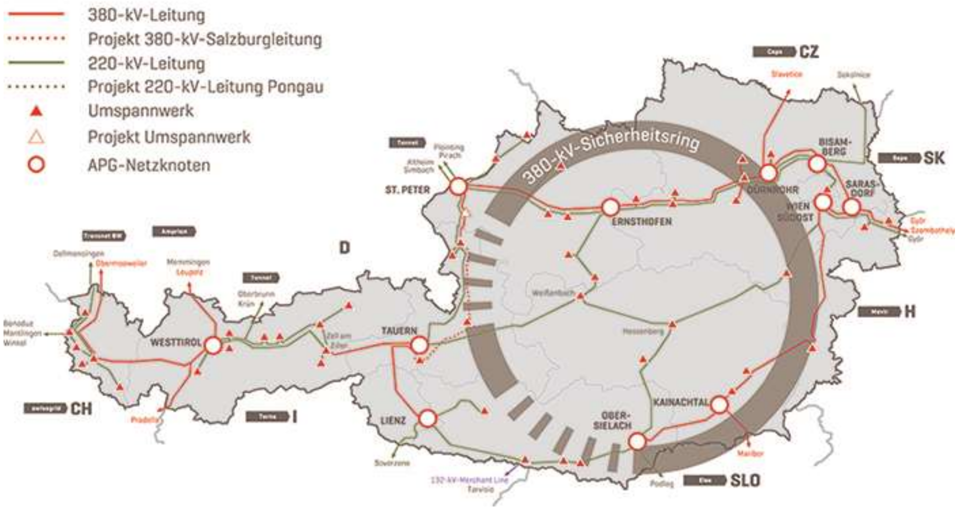


Maximum annual loads in the public grid of Austria were around 11.2 GW[6] in 2016 while minimum load was around 5.8 GW. Electricity demand peaks occurring in winter month. Demand peaks occured around morning hours up to around noon (8 a.m. to 11 a.m.) throughout the year and in evening hours during winter months (5 p.m. to 8 p.m.). Demand peaks for electricity are at least to a certain extend triggered by power to heat for electrical heating and domestic hot water supply in the residential and service sector.

The electrical grid was originally designed to connect demand centres with the main run-of-river plants and the large storage plants in the Alps. The Austrian TSO is currently working on projects to close a 380 kV loop in Austria to prepare the Austrian electricity grid for further integration of intermittent renewables and increased coupling with neighbouring countries. For an overview on the Austrian transmission network see Figure 24.

[6] https://www.e-control.at/statistik/strom/betriebsstatistik/betriebsstatistik2016

Figure 24: Overview of the Austrian transmission system including projects to close a 380kV loop across Austria, Source: https://www.apg.at/de/projekte/380-kv-salzburgleitung

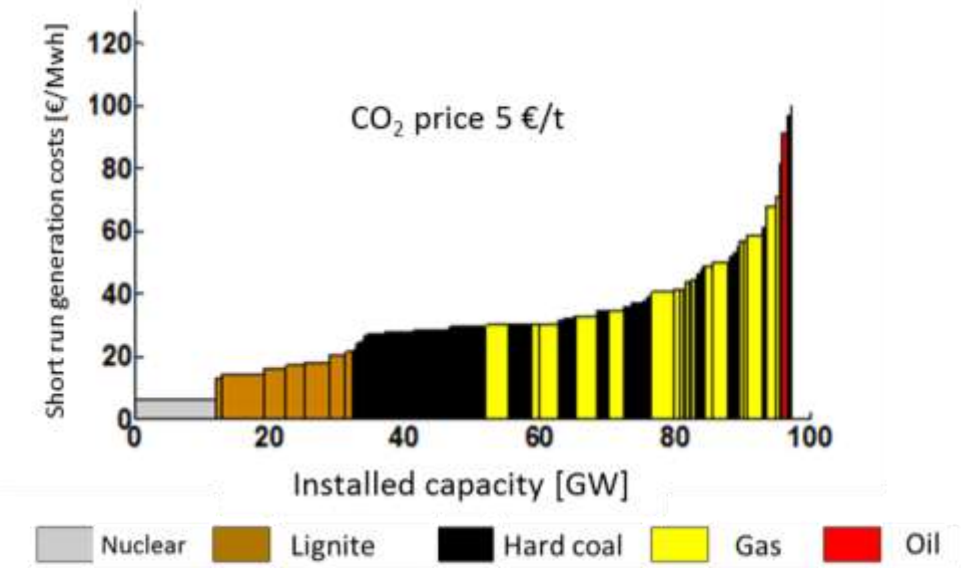


It should be noted that the Austrian electricity system is closely coupled to its neighbouring countries. In particular Austria and Germany form a common price zone and the prices are to a large extend driven by electricity demand and supply in Germany. Analysing both countries as a whole the renewable shares are much smaller and generation is still dominated by fossil fuel generators in Germany. The price and also dispatch of electricity generation is mainly determined by trading on a common electricity exchange platform at the EEX in Leipzig, Germany (https://www.eex.com/). The price formation of day ahead prices is based on competitive bidding on the exchange. Due to the relatively competitive situation between suppliers the price formation typically follows the marginal general costs of the last plants which gets accepted at the auctions for each individual hour (block offers are also possible). The merit order curve shown in Figure 25 therefore provides a relatively good approximation of the supply curve for electricity in Austria and Germany. The price at each hour would be given by the intersection of electricity demand net of renewable generation (which is not included in this graph). It can be seen that at low to mid residual loads of up to 50 GW in Austria and Germany mainly coal plants are in operation. At current prices gas fired power plants are only operated at times of higher loads or if they are needed to provide heat for industries or heating grids (CHPs) or for grid stabilisation including redispatch services or provision of balancing energy.

Since 2008 electricity prices in Austria and Germany have been continuously declining for various reasons including lower fossil fuel and carbon prices and increasing feed in from renewables. The increasing feed-in from renewables, in particular at times of high wind feed-in in the north of Germany leads to increasing issues concerning grid congestions from north to south across the common market area and neighbouring countries including Poland and Czech Republic. Following increasing costs of this congestion management and increasing pressure from Germany it is very likely that the common market of zone Austria and Germany will be split up at least for a certain period in the near future. It can be expected that this will lead to slightly higher electricity market prices in Austria. (e.g. Blume-Werry et al. (2016)) However, it is not expected that the price increase will be a game changer and significantly affect the generation costs of large scale heat pumps throughout a year as there will still be significant trading taking place between Austria and Germany which should lead to equal or similar prices in Austria and Germany in most hours of the year.

Figure 25 also reveals that the overall level of electricity prices is bound to the developments of global market prices for natural gas and hard coal which is the fuel used by the majority of price setting power plants in Austria and Germany. Although the increasing feed-in from Wind and PV will reduce prices in particular hours significantly (e.g. see Hartner et al. (2017), Hirth (2013)), the main drivers for average electricity prices will be fuel prices and CO_2 costs (see Everts et al. (2016)). Higher CO_2 costs would in particular increase the costs for power plants fired with hard coal and even more lignite power plants which show the highest CO_2 emission factors per MWh electricity due to their low conversion efficiencies. This would significantly increase the lower end of electricity prices in Austria and Germany. In ambitious policy scenarios with higher CO_2 prices than today (>20 €/t) increasing electricity prices can be expected. For very high CO_2 prices a shift from coal to natural gas can be expected which would make natural gas prices the crucial factor for electricity prices in the future. Given the importance of CO_2 prices and the role of renewable energy sources which are subsidies to a large extent, the development of electricity prices in Austria and Germany strongly depends on the policy decisions both on EU and national level. It should also be noted that market prices only account for a relatively small share (≈20%-40%) of end user costs for small scale end users. End user prices are even subject to regulatory measures and also include the potential costs for electricity grids or subsidies of renewable generation which are not necessarily reflected in the wholesale market price for electricity (see 2.7).

Figure 25: Approximation of Austrian and German merit order of conventional power plants at a CO2 price of 5 €/t and fossil fuel prices of the year 2012; Source: Platts database and own calculations

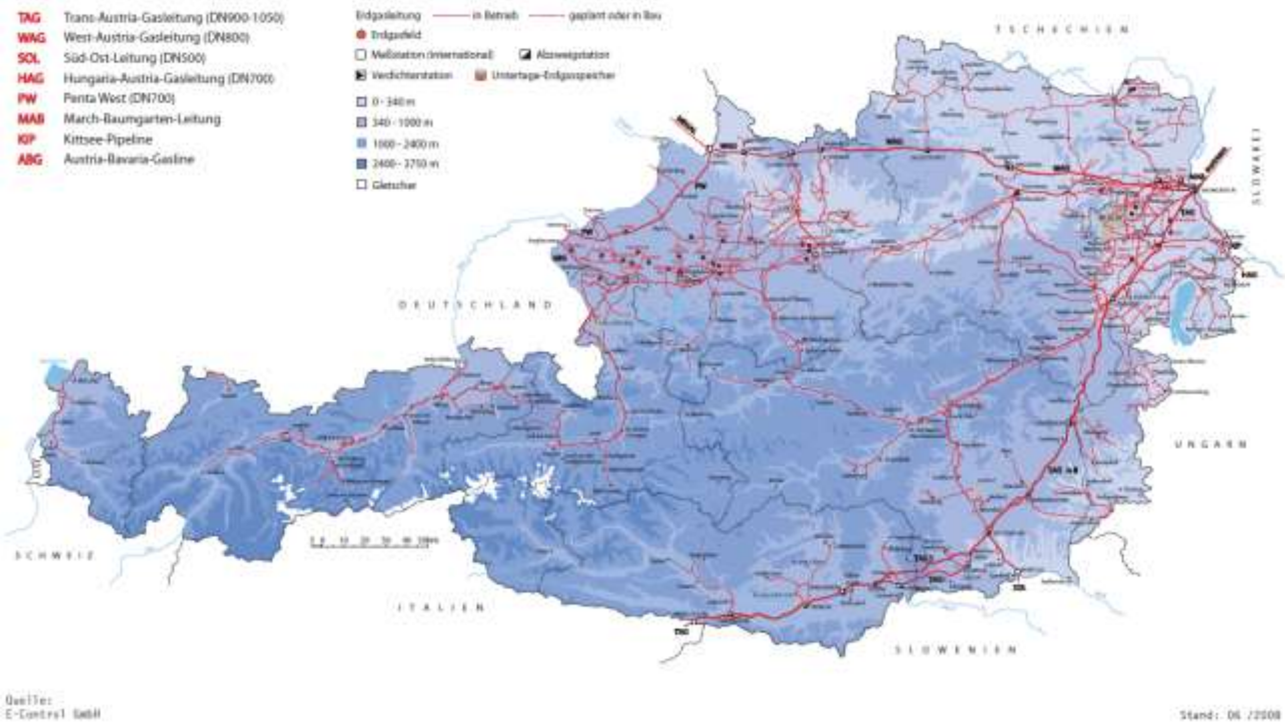


2.6.3. Infrastructure gas supply

The Austrian gas network is a historically grown system which, due to its geographical location, is an important hub for the distribution of natural gas, primarily to southern and western Europe. However, gas flows from west to east have also increased in recent years. The development of the gas network focuses on securing and increasing security of supply for Austrian gas customers. The Austrian natural gas network consists of long-distance pipelines, which in most cases are also reverse-flow capable, distribution pipelines including compressor and spool stations, pigging equipment, control and measuring equipment as well as facilities required for access to long-distance and distribution pipelines. Long-distance pipelines are pipelines used for the transport of natural gas through a high-pressure pipeline or network, provided that such pipelines are also intended for cross-border transport or transport to other pipelines or distribution lines. The coordination of network control, including grid and balancing energy management, is carried out by the

Market Area Manager (http://www.aggm.at/).
Figure 26 shows the Austrian natural gas infrastructure with gas fields, measuring stations, junction stations, compressor stations and underground gas storages. In about 1 000 of 2 380 Austrian municipalities more than 80% of the heat demand lies within 2 km of an existing gas pipeline indicating a relatively high geographical availability of natural gas also considering that all major cities which make up for the main share of heat demand are connected to the natural gas grid. The Austrian pipeline network has a length of approx. 2,000 km and the distribution network has a length of approx. 44,000 km (E-Control, 2017).

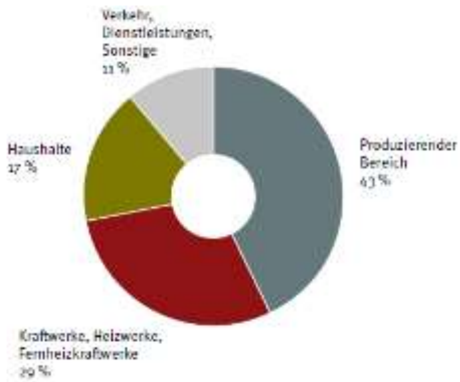
Figure 26: Natural gas pipelines & natural gas deposits in Austria (E-Control, 2017)



Statistical data

The main consumer of natural gas in Austria was the manufacturing sector in 2016. This sector uses natural gas to produce process heat or as a raw material in production and has a share of 43% of the total demand. 29% of the total gas demand was used in 2016 for electricity and district heating generation. For households (about 17% of natural gas demand), the applications of space heating, water heating and cooking are the main focus (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, September 2017).

Figure 27: Natural gas delivery to consumers in 2016 (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, September 2017)



Natural gas production is a major economic factor in Austria. In 2016 the extraction amounted to 1.25 billion m³. This enabled 15% of Austria's natural gas supply to be covered. The remaining 85% is attributable to imports from CIS countries and other countries. OMV Austria E & P contributed 66.8% and RAG 33.2% to domestic extraction. In 2016 44.3% of the domestic natural gas was extracted in the Vienna basin and 55.7% in the Molasses zone.

The Austrian natural gas network (without long-distance lines) reached an overall length of around 44 000 kilometers in 2016. The length has almost tripled in comparison to 1990 (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, September 2017).

Figure 28: Natural gas utilization in Austria from 1990 to 2016 (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, September 2017)

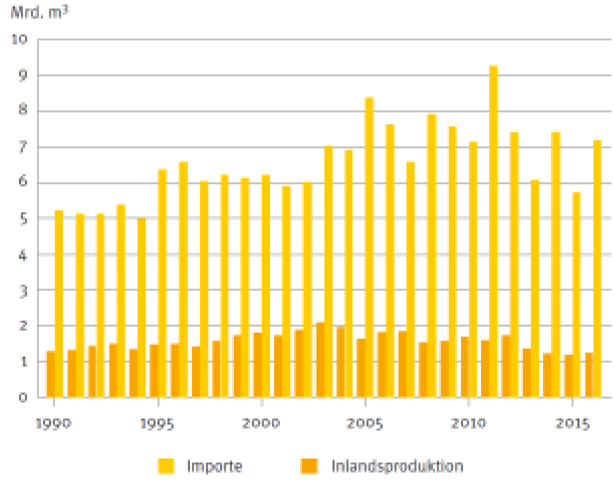
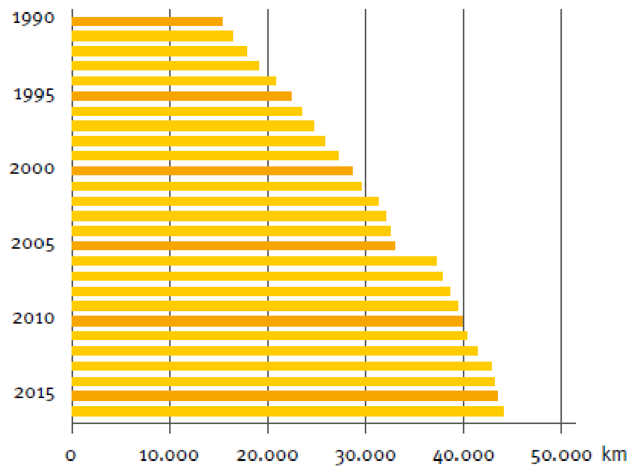


Figure 29: Development of gas grid length in Austria (without long-distance lines) (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, September 2017)



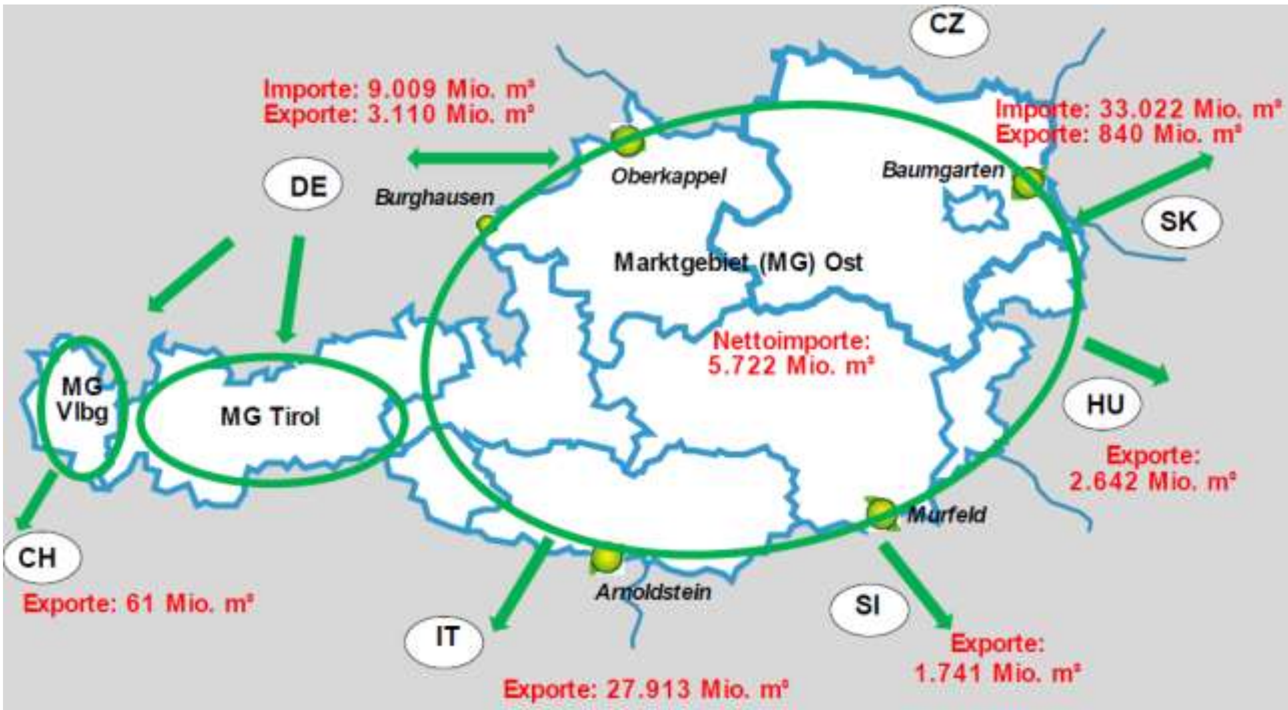
Through natural gas storage, it is possible to compensate for the fluctuations between gas supply and gas demand - for example, to meet significantly higher demand in the winter months. As of December 2016, the natural gas storage companies operating in Austria have storage facilities with a total technical capacity of 94.6 TWh (around 8.4 billion m³) working gas volumes (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, September 2017).

Figure 30: Natural gas transit network (transmission lines) and domestic high-pressure pipelines as well as location of the natural gas storage in Austria (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, September 2017)

Cross-border gas flows

Details of cross-border gas flows are shown in **Fel! Hittar inte referenskälla.**. Gas flows from the SK and DE to Austria. From Austria gas flows to IT, DE, HU, SI, SK, FL and CH (bmwfw, 2016).

Figure 31: Physical cross-border gas flows in 2015 (bmwfw, 2016)



Gas storages

Natural gas storage capacities in Austria have increased since the beginning of this decade from 4.6 billion m³ to currently over 8 billion m³. The favorable geological conditions in Austria were a key factor in this positive development, both in terms of competition and security of supply.

As the graph on the basis of the year 2016 shows, the quantities stored at the end of the month in gas storage facilities located on Austrian territory normally amount to a multiple of the natural gas consumed in Austria in the individual months. Of course, the gas volumes stored in Austria are not only intended for consumers in Austria, but Austria's natural gas supply should be largely secure.

A cornerstone of gas supply is imports on the basis of long-term contracts concluded by Austrian importers with suppliers in Norway (~ 1 billion m³ p. a.) and in the Russian Federation (~ 5.3 billion m³ p. a.).

With the ongoing liberalisation of the natural gas market, the short-term procurement of natural gas on the natural gas exchange has become increasingly important. The volumes traded there increased from around 94 million m³ in 2010 to more than 1.8 billion m³ in 2016 (bmwfw, 2017).

Figure 32: Month-end storage level and monthly consumption in million cubic meters 2016 (bmwfw, 2017)

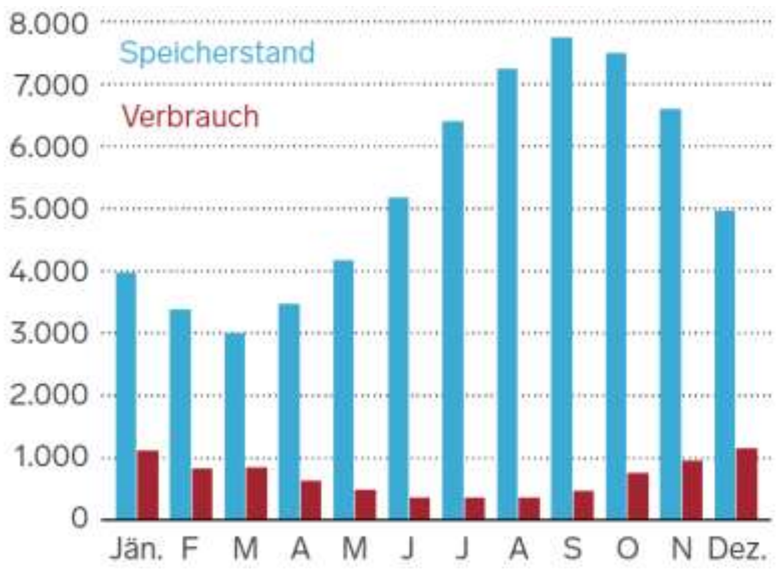
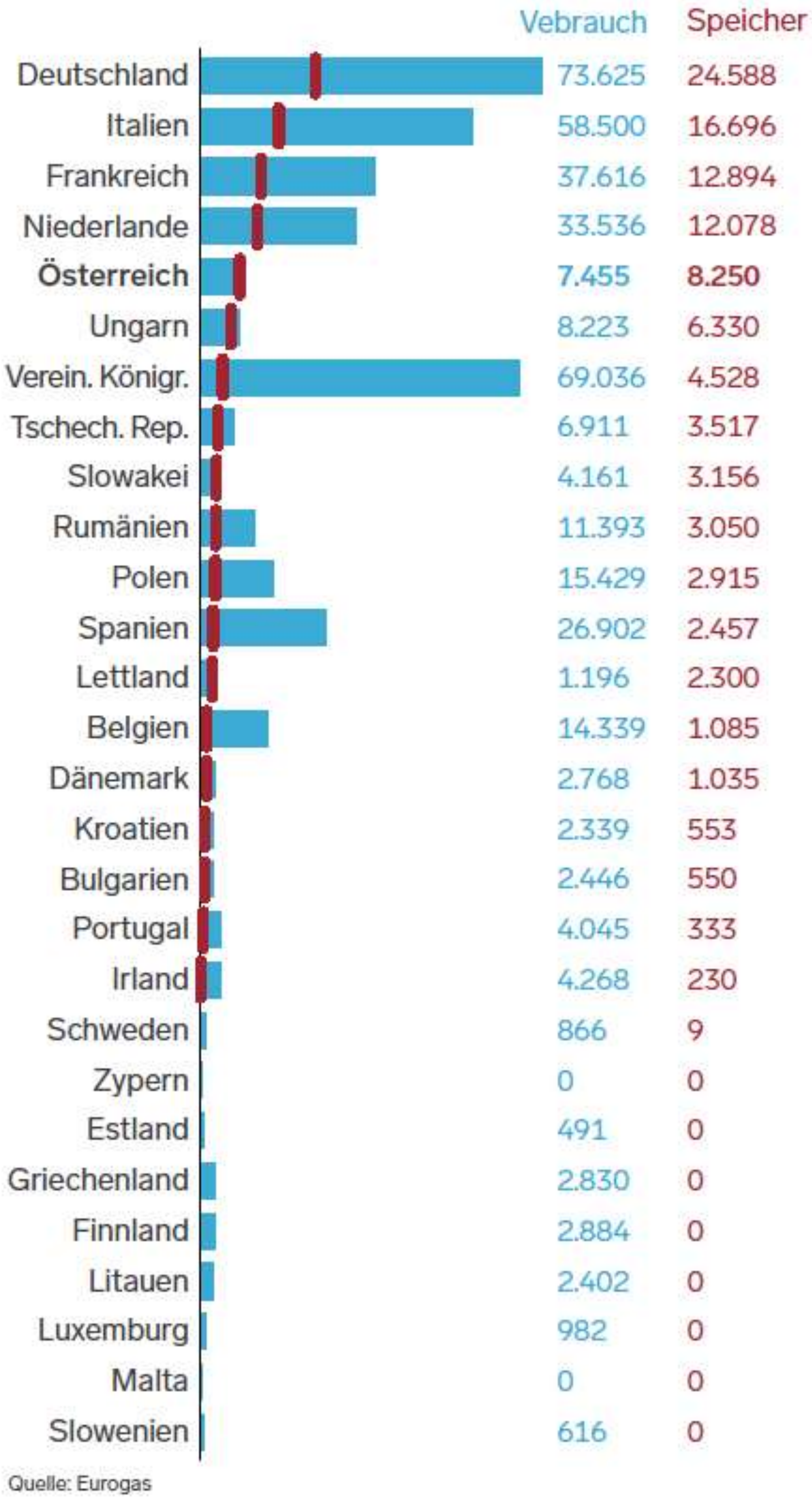


Figure 33: Storage and consumption in an international comparison (Storage capacity (working gas volume) and consumption in million cubic meters in 2014) (bmwfw, 2017)



2.7. Energy prices and tariffs for end users in Austria

In this section an overview of energy prices and tariffs for end users in Austria is provided. Table 8 and Table 9 show the minimum, maximum and weighted average of energy prices for households and services in Austria from 2013 to 2016.[7] Both electricity and natural gas energy prices showed a decreasing trend in recent years due to decreasing wholesale prices on the electricity and natural gas markets. It should however be noted that the energy component is only a certain part of the tariffs end users of electricity and natural gas are paying in Austria. For electricity the energy costs only amount to around 32% of total costs for households. 28% of the full tariff consist grid costs and more than 40% of the costs are taxes and duties including support costs for renewable energy sources and CHPs. For natural gas energy costs amount to around 41% while grid costs make up for around 31% and taxes and duties for around 29% of total costs for households.

Table 8: Energy prices for natural gas in Austria from 2013 to 2016 in cent/kWh, Source: https://www.e-control.at/preismonitor

Households	1.HJ 2013	2.HJ 2013	1.HJ 2014	2.HJ 2014	1.HJ 2015	2.HJ 2015	1.HJ 2016	2.HJ 2016
minimum	2.76	2.72	2.72	2.50	2.26	2.32	2.00	1.54
maximum	4.34	4.34	3.93	3.96	3.95	3.99	3.92	4.00
w eighted average	3.55	3.69	3.60	3.60	3.51	3.47	3.30	3.12

Services	1.HJ 2013	2.HJ 2013	1.HJ 2014	2.HJ 2014	1.HJ 2015	2.HJ 2015	1.HJ 2016	2.HJ 2016
minimum	2.77	2.73	2.38	2.20	2.26	2.25	2.00	1.59
maximum	4.34	4.43	4.03	3.83	3.82	3.82	3.93	3.73
w eighted average	3.51	3.64	3.49	3.43	3.33	3.21	3.01	2.79

Table 9: Energy prices for electricity in Austria from 2013 to 2016 in cent/kWh, Source: https://www.e-control.at/preismonitor

Households	Jan/2013	Jul/2013	Jan/2014	Jul/2014	Jan/2015	Jul/2015	Jan/2016
minimum	4.03	4.03	3.82	3.82	3.75	3.75	2.40
naximum	10.15	10.50	9.88	9.14	9.84	9.77	9.79
w eighted average	7.59	7.45	7.36	7.25	7.01	6.89	6.66

Services	Jan/2013	Jul/2013	Jan/2014	Jul/2014	Jan/2015	Jul/2015	Jan/2016
minimum	3.99	3.99	4.02	4.02	3.67	3.67	2.29
naximum	9.90	12.35	8.92	8.92	8.89	8.78	8.79
w eighted average	7.15	6.98	6.81	6.53	6.28	6.09	5.79

The costs for large scale consumers including industrial sites and operators of district heating grids vary substantially. In general, they can be substantially lower compared to small scale end user prices. Full variable costs for natural gas from a district heating operators point of view were between 30 €/MWh and 40 €/MWh in 2015. The electricity costs for the operation of large scale heat pumps also heavily depend on individual contracts between a district heating operator and electricity supplier. In addition, it depends on the regulation of electricity costs for power to heat. Within the current regulation in Austria full variable costs for operating large-scale heat pumps are estimated to be around 50 €/MWh to 60 €/MWh.

Other relevant energy carriers for heating and cooling in Austria are wood log, pellets, wood chips, fuel oil and heat from district heating. Prices in Austria vary regionally and over end user groups. A consistent

[7] https://www.e-control.at/preismonitor

overview with the necessary level of detail is out of scope for this report. Here only an exemplary scenario for energy prices for small scale end user including taxes in a scenario with existing policy measures in Austria used in a study by Müller et al. (2017) is provided in Table 10. This scenario assumes significant increases in oil and natural gas prices as well as an increase in CO_2 prices until 2050. Recent developments of fossil fuel prices have been relatively stable and CO_2 prices have been very low for several years indicating that future developments are highly uncertain and fuel price increases cannot be taken for granted.

Table 10: Scenario on variable costs for energy carriers from 2010 to 2050 including taxes and duties for small scale end users in Austria. Source: Müller et al. (2017)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Natural gas	60	67	78	83	87	91	93	94	95
Fuel oil	74	68	76	82	86	88	90	90	91
Coal	39	37	41	46	51	53	54	55	56
Wood log	36	41	46	48	50	52	53	53	53
Wood chips	31	32	35	37	38	40	40	41	41
Pellets	45	46	51	53	56	58	58	59	59
Electricity	174	180	180	192	202	208	213	215	216
District heat	54	58	66	70	74	76	77	78	79

3. Market potential for district heating and cooling

This chapter discusses the potential for district heating and cooling in Austria. The here presented summary of the potentials is based on a study by Büchele et al. (2015) on the assessment of the potential for application of high-efficiency cogeneration and efficient district heating and cooling in Austria. First the results for technical and economic potentials of district heating in Austria up to 2025 are presented. Then potentials for district cooling and the relevance of district heating networks for a low carbon energy supply in Austria are discussed.

3.1. Potential for district heating

To determine the technical and economic potential demand regions with heat demand densities higher than 10 GWh/km² were determined. Of these areas those who have a plot ratio[8] of more than 0.25 and an annual heating demand of more than 10 GWh are called main regions and are classified as highly suitable for district heating and were analysed in detail. The remaining areas are called secondary regions. Although they show lower heat densities on average also here potentials for district heating exists. (see 2.3, 2.6.1)

3.1.1. Technical potentials

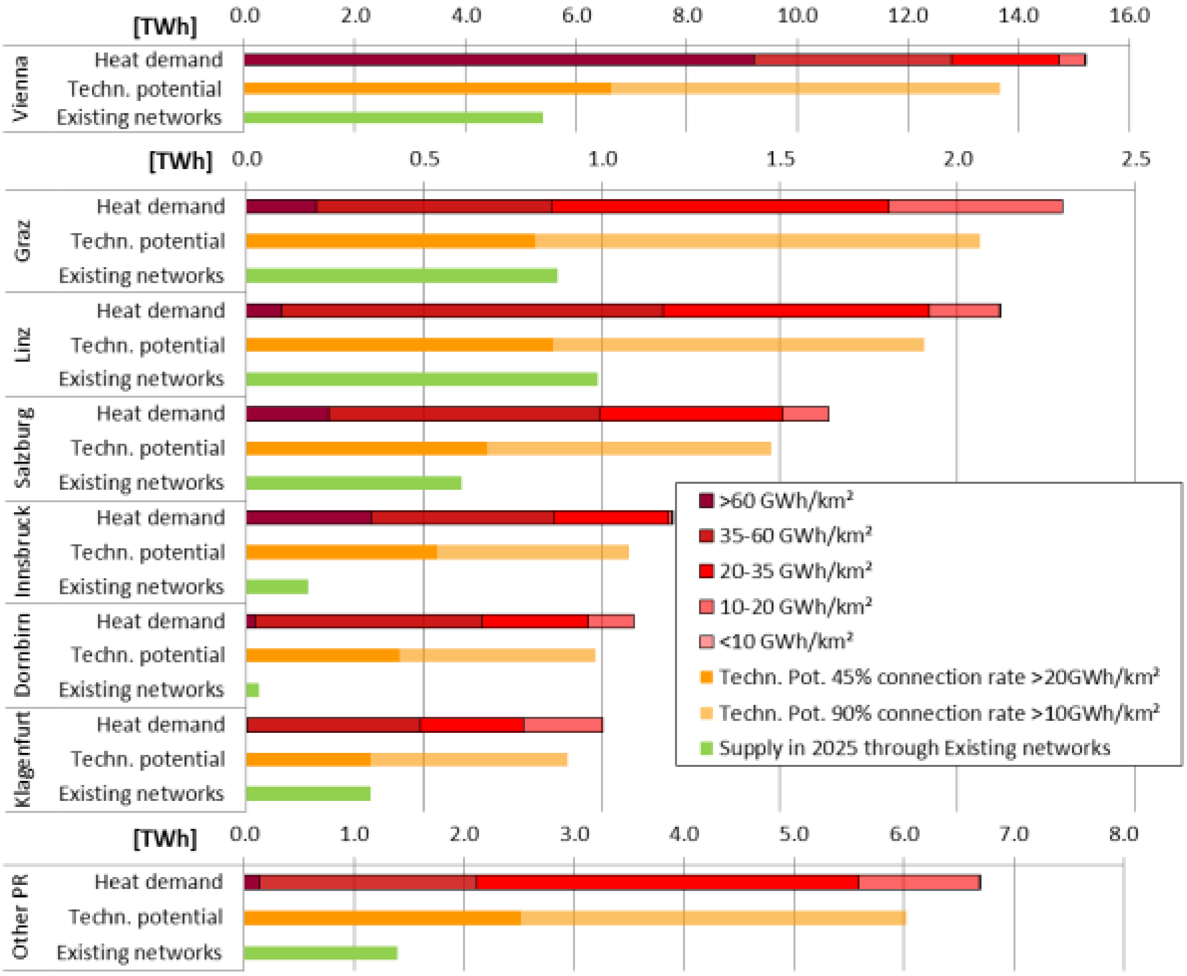
The technical potential for district heating is calculated on the basis of the energy demand for space heating and hot water in 2025 assuming an overall heat demand reduction of 20%. To calculate the full technical potential for district heating it was assumed that in the defined regions a connection rate of up to 90% of the heat demand in areas with heat densities of more than 10 GWh/km² can be achieved. As reference a reduced technical potential was calculated applying a connection rate of 45%.

Assuming a connection rate of 90% of the heat demand in areas with heat densities higher than 10 GWh/km² leads to a technical potential of 63 TWh including 13 TWh which are already supplied by existing infrastructure. A full exploitation of this technical potential would translate into a market share of 81% of the total heat demand in 2025 indicating that it will not be possible to exploit this potential until 2025 given a current market share of below 20%. The calculation of the reduced technical potential (45% of the heat demand in areas with heat densities higher than 20 GWh/km² connected to district heating) results in slightly over 22 TWh including the existing supply and representing a share of 28% of the heat demand in 2025. Figure 34 shows the heat demand split up into the different heat densities, full- and the reduced technical potential for district heating and the share of demand supplied by existing grids in 2025 for the seven biggest regions classified as highly suitable for district heating and summed up for the remaining cities which have been classified as primary district heating regions and more rural areas which have been classified as secondary district heating regions (for details on the classification see Büchele et al. (2015)).

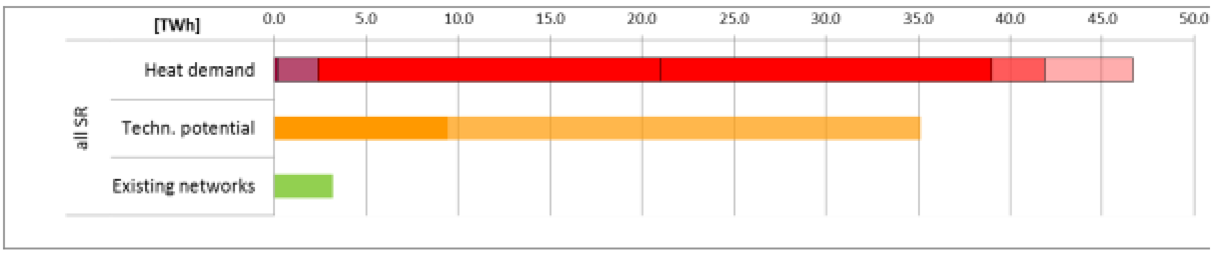
[8] plot ratio: ratio of the gross floor area of all buildings within a certain region and the land area of a given region.

Figure 34: Technical potential for district heating in Austria for primary regions and secondary regions; Source: Büchele et al. (2015)

Primary regions (PR)



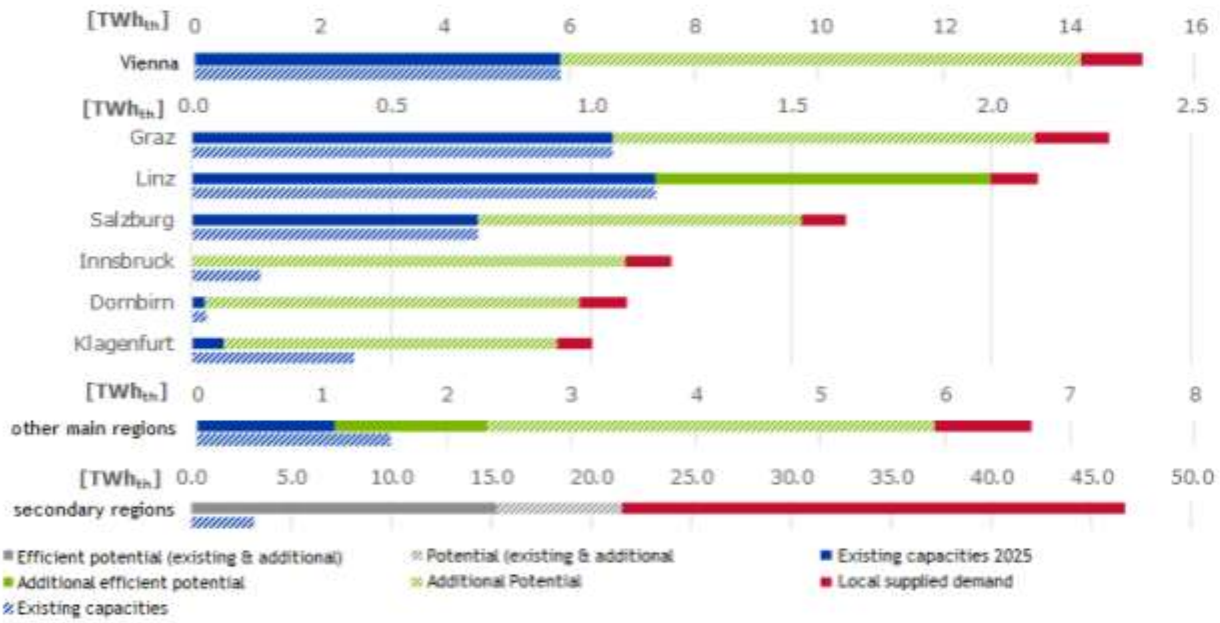
Secondary regions (SR)



3.1.2. Economical potential

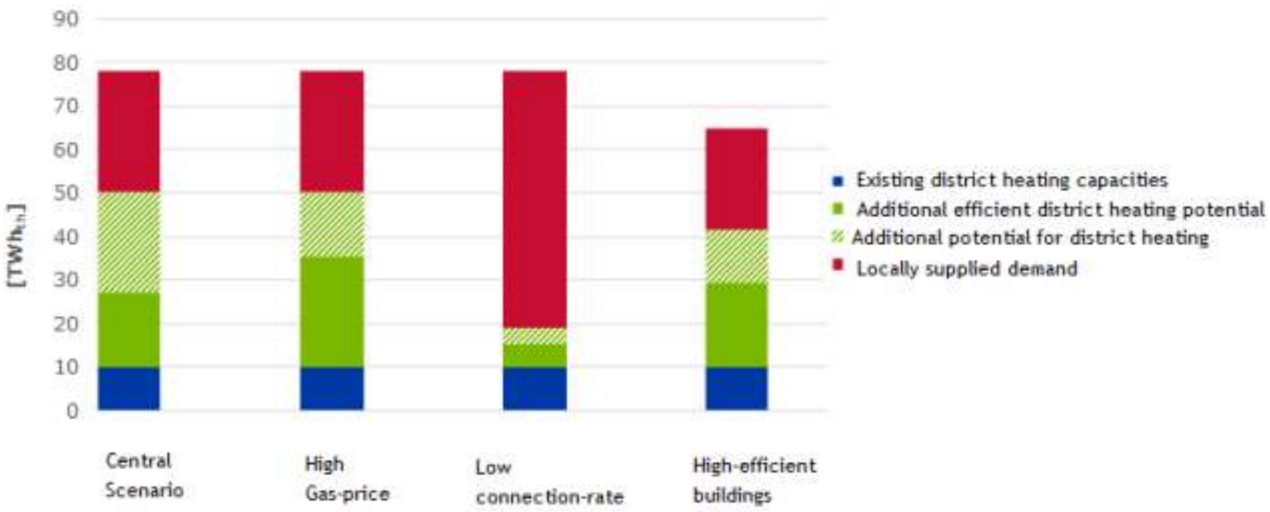
The economic potential is calculated based on the full technical potential assuming an achievable connection rate of 90% by a cost benefit analysis taking into account expected costs for energy until 2025. For all determined regions an individual merit order of available technologies is established and applied to determine the economic potentials. Although the merit order depends on the available technologies, heat density, distance and applicable full load hours it can be stated that generally the cheapest technologies in terms of heat generation costs are industrial excess heat, geothermal heat, heat from waste incineration and biomass if available. When none of these technologies is available central gas boilers are the most cost-effective technology under the expected conditions. However, this analysis does not include barriers like insecurities or other restrictions that may occur when trying to integrate sources like industrial excess heat or geothermal heat in reality which could affect the merit order of heat supply technologies in individual regions. Figure 35 shows the results of the economic potential for the seven biggest main regions classified as highly suitable for district heating and summed up for the other secondary regions. The full potential shows a total economic potential for district heating of 52 TWh accounting for 67% of the Austrian heat demand in 2025.

Figure 35: Economic potentials for district heating in Austria; Source: Büchele et al. (2015)



However, the results of the economic potential are highly sensitive on the energy price of natural gas, on the achievable connection rate and on the development of heat demand in buildings and therefore have to be looked at with caution. Figure 36 shows the sensitivity of the economic potential on different parameters. Under the assumption of connection rate of 90% district heating often is economical feasible down to heat densities of 10-20 GWh/km². But when applying a lower connection rate of only 45% the sensitivity analysis shows a big drop in economic potentials to 20 TWh accounting for only 26% of the heat demand of 2025. This is of great interest because with lower connection rates the distribution costs increase and the economic potential for district heating decreases.

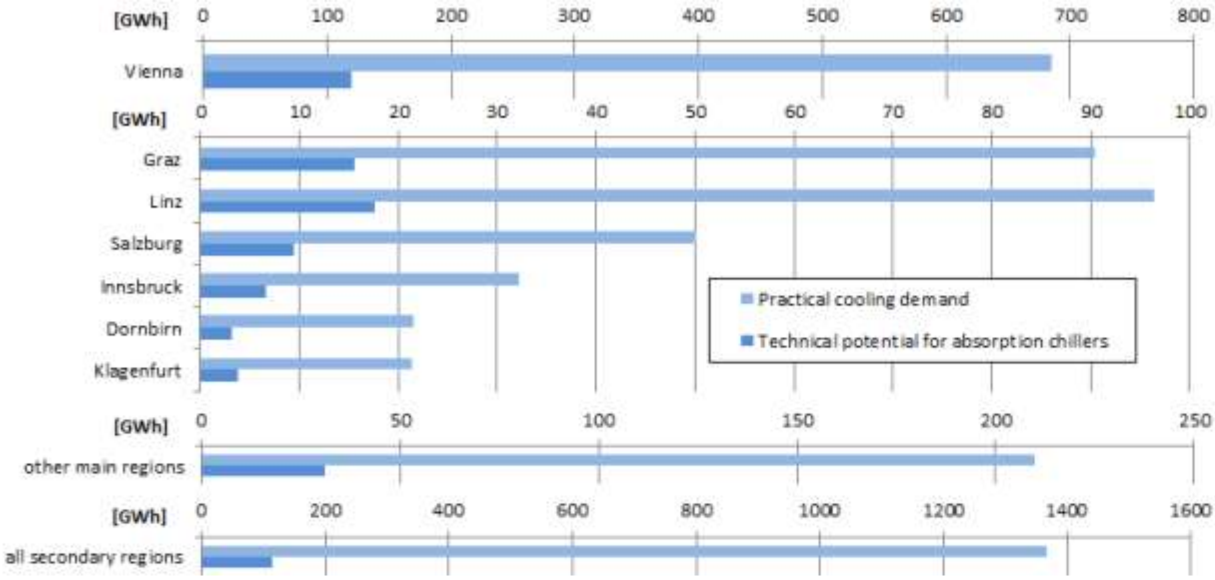
Figure 36: Scenarios for economic potentials for district heating in Austria; Source: Büchele et al. (2015)



3.2. Discussion of potential for district cooling

The first step to estimate potentials for district cooling is to estimate total space cooling demand in Austria. The theoretical cooling demand in buildings (useful energy demand) is calculated assuming that all buildings cover their cooling demand. However, in reality, only a certain share of buildings will cover their theoretical cooling demand by installing an air conditioning system. Therefore, diffusion restrictions limit the number of air-conditioning systems that are installed in buildings. The resulting final energy consumption (electricity) for air conditioning purposes in Austria accounted for approximately 500 GWh in 2012, and is estimated to rise to 858 GWh by 2025. Assuming an average performance coefficient for air conditioning systems of 3, this results in a useful energy demand for cooling of 2.6 TWh for the year 2025. To further calculate the potential for district cooling by absorption chillers only buildings with high cooling loads and full-load hours of around 1 000 h/a are considered. According to the building stock database 37% of retail shops, 38% of the hotel sector, 32% of public buildings and 56% of office buildings are classified as large buildings. It is assumed that 80% of the cooling demand of these buildings is suitable for being supplied by district cooling resulting in a technical potential of 320 GWh supplied by district cooling in the year 2025. Figure 37 illustrates the useful energy demand for cooling in 2025, and the share suitable for absorption chillers for different regions in Austria.

Figure 37: Useful energy demand for cooling and technical potential for absorption chillers in Austra; Source: Büchele et al. (2015)



3.3. Contribution of district heating grids to a low carbon energy supply in Austria

District heating is considered to be a cornerstone for a low carbon heat supply in Austria in particular in urban areas where decentral biomass boilers are not an option. Also, decentral air source heat pumps can be problematic in urban areas due to noise pollution and space limitations. A large share of urban areas in Austria is supplied with decentral natural gas boilers which could be substituted by a low carbon district heat supply.

District heating grids with flexible heat supply options (CHPs, boilers, heat pumps, electric boilers and storage) can also provide flexibility for the electricity system when variable renewable shares increase in the coming years. In addition, large gas fired CHP plants are considered to be an efficient bridging technology to reduce emissions in the electricity and heat supply. Without district heating however, heat from large scale CHPs could only be used by large industrial sites which would limit their potential significantly.

District heating grids also allow for the integration of excess heat sources which might otherwise be untapped. Technical waste heat potentials from large industries shown in Table 11 were estimated in Büchele et. al 2015. The locations of the main energy intensive industrial sites in Austria can be seen at www.austrian-heatmap.gv.at. The study estimates a significant additional potential for the use of waste heat with waste heat potentials of 2.8 TWh with temperature levels above 100°C and 8.5 TWh below 100°C compared to a current exploitation of 1.5 TWh. The authors add however, that there are large uncertainties regarding the estimation of both the technical and in particular the economic potentials of waste heat in Austria.

Table 11: Technical potential for application of waste heat in Austrian industry by sector up until 2025: Source: Büchele et al. (2015)

[GWh/a]	Potential >100°C	Potential <100°C	Currently fed in
Metals production or processing	1279	184	251
Chemicals industry and mineral oil processing	707	3826	905
Non-metallic minerals	415		22
Manufacture of machinery and equipment n.e.c.,	1	10	
Food materials industry	0	11	
Pulp and paper industry	382	4121	228
Wood processing	44	317	136
Total	**2828**	**8469**	**1542**

Irrespective of the uncertainties regarding waste heat potentials it is clear that the larger share of waste heat potentials from industrial processes and other sources (e.g. lakes, ground water, rivers) will be available at temperature levels below 100°C (also see 4.2). In the study power to heat potentials in Austria (Totschnig et al. 2017) the potential output from heat pumps using large rivers or lakes as a heat source near regions with high potential for district heating networks was assessed. The total technical potential of those heat sources was assessed to provide rated thermal power output of around 8-9 GW. While these potentials have to be assessed in more detail on a project by project basis the analysis shows that those heat sources alone provide a substantial resource for the integration of heat pumps in heat networks in Austria. On the other hand, it also has to be noted that the sources might not be available throughout the year due to technical restrictions. In particular the very low water temperatures in winter are a major issue and might restrict the use of heat pumps in times of very high heat demands. Again, that shows the need for backup capacities in combination with heat pumps in district heating networks. For a discussion on additional heat sources in urban areas please also see Ochsner et al. (2013) or Ostermann et al. (2010).

The availability of low temperature heat sources and also highlights the importance of future temperature levels of district heat networks for the exploitation of those potentials. Given the barriers of lowering temperature levels in existing networks the use of large scale heat pumps will be inevitable to harvest those low temperature heat potentials in the future. The following chapter further discusses the potential role of heat pumps in Austrian heat networks.

4. Role of Heat Pumps in district heating

This section discusses the potential role of large scale heat pumps in Austrian district heating grids. At the moment heat pumps are mainly used in decentral heat supply. Biermayr et. al. (2016) estimate that by 2050 there were around 240 thousand heat pumps in operation. The majority are small scale heat pumps with nameplate capacities below 20 kW_{th} installed in single family houses. In 2015 only 180 heat pumps with installed capacities of more than 50 kW_{th} were sold on the Austrian market. Additionally, 18 heat pumps were installed in the industrial sector which can be classified as large-scale heat pumps. In general, the market for large scale heat pumps in Austria is rather small.

However, heat pumps are currently in a test phase for district heating networks. Several network operators are considering the use of large scale heat pumps in the light of falling wholesale electricity prices and technology improvements in terms of temperature levels and capacities of heat pumps. It is very likely that heat pumps will play a significant role in heat generation for heat networks in the future in combination with combined heat and power plants (CHPs) and heat storage following the well-known examples of Danish heat networks.

In the following section basic economic considerations for large scale heat pumps in heat networks are discussed.

4.1. When is it economically beneficial to implement heat pumps in district heating/cooling

Short run generation costs of Heat pumps vs. CHPs and boilers

The short run heat generation costs of a heat pump (c_{heat_P2H}) are given by the ratio of electricity price (p_{el}) and coefficient of performance (COP) of the heat pump. Both are typically a function of time. The COP of a heat pump varies depending on the temperature of the heat source for the heat pump (ground water, geothermal heat, excess heat) as well as on the temperature level of the heating grid. If generation costs are calculated only based on wholesale electricity price the short run costs are very low because of currently low-price levels. However, typically the prices for operators of heat pumps include surcharges, grid costs and taxes. The short run costs from the operator's perspective is therefore heavily affected by the regulation within each country. Please see section 2.7 on energy prices in Austria.

$$c_{heat\_P2H} = \frac{p_{el}}{COP}$$

For a heat pump to be profitable at least the generation costs have to be lower than the costs of a reference technology such as thermal boilers fired by natural gas, oil, coal or biomass.

$$c_{heat\_ref} = \frac{p_{fuel\_ref}}{\eta_{th\_ref}}$$

Note that also the generation costs of the reference technology typically vary over time. Firstly because of price variabilities in fuel prices which can be substantial even within a year. Secondly, in heat networks with several generation technologies the reference technology for the operation of a heat pump changes over time in high and low load situations. Similar to the electricity market there is a merit order of generation units in large heat networks which set the reference opportunity costs of heat production at each point in time.

Given the high shares of CHP plants in Austria the reference technology will often be a combined heat and power (CHP) plant. The short run generation heat generation costs of CHPs can be defined as:

$$c_{heat\_KWK} = \frac{p_{fuel\_CHP}}{\eta_{th\_CHP}} - p_{el}\frac{\eta_{el\_CHP}}{\eta_{th\_CHP}}$$

The short run heat generation costs of CHPs (c_{heat_KWK}) also depend on the fuel price (p_{fuel_CHP}) for the plant (natural gas, coal, and biomass) and the thermal efficiency (η_{th_CHP}) of the CHP plant. From those heat generation costs the income or the value of electricity production from the plant has to be subtracted. The electric and thermal efficiency of CHPs are connected with the power to heat ratio of the plant ($\frac{\eta_{el\_CHP}}{\eta_{th\_CHP}}$) which can be flexible to a certain extent depending on the type of CHP plant. For all CHP plants the heat generation costs fall with higher electricity prices.

Compared to the generation costs of heat pumps the costs of heat production of CHPs show an inverse relationship which is discussed in the following section.

Example for short run generation costs of CHPs, heat pumps, and heat only boilers

In this section a concrete example for a short run heat generation costs comparison based on hourly wholesale prices for the Austrian and German market in the year 2014 is given. On top of the wholesale price a surcharge of 50 €/MWh for electricity consumption of heat pumps (see section 2.7 for a discussion on electricity prices and tariffs in Austria) is assumed. The parameters assumed for CHPs, heat pumps and a reference boiler can be seen in Table 12. It is assumed, that the CHP and the reference technology operate on the same energy carrier with a constant fuel price of 22 €/MWh, the heat pump operates on a constant COP of 3.5 and the CHP operates on a fixed power to heat ratio of 0.5/0.38 = 1.3.

Table 12: Assumptions for calculation of hourly short run heat generation costs

COP heat pump	η_{el_CHP}	η_{th_CHP}	η_{th_ref}	P_{fuel} [€/MWh]	P_{el} [€/MWh]	surcharge electricity (taxes, grid, etc.) [€/MWh]
3.5	0.50	0.38	0.95	22	Hourly EEX spot prices 2014	50

Figure 38 shows the outcome of this comparison for the sorted duration curve of electricity prices in the year 2014 illustrating the inverse relationship between the heat generation costs of heat pumps and CHPs. Note that the heat generation costs of the reference boiler are independent from the electricity price and are therefore shown as a straight line throughout the whole year. Figure 38 reveals that under those assumptions the break-even point between the reference technology and the heat pump would be at a wholesale electricity price in the range of 30 €/MWh (equals 80 €/MWh of electricity costs for the heat pump wholesale price: 30 €/MWh + 50 €/MWh of additional price components). In more than 4 000 hours of this year the heat generation costs of the heat pump would be lower than the generation costs of the reference boiler. The break-even point with CHP plant would be at a wholesale electricity price of around 27 €/MWh. The heat pump in this example would have been cheaper to operate in around 2 500 hours of the year. Note that the outcome of this comparison heavily depends on the assumptions of fuel prices, assumptions on the surcharges for electricity consumption of the heat pump and the price duration curve of the wholesale electricity price itself. All those parameters are subject to constant change which makes it difficult to provide a general estimation of the profitability of large scale heat pumps in heat networks.

Figure 38: Duration curve of short run heat generation costs with wholesale electricity prices of the year 2014 including a surcharge of 50 €/MWh; Source: own calculations

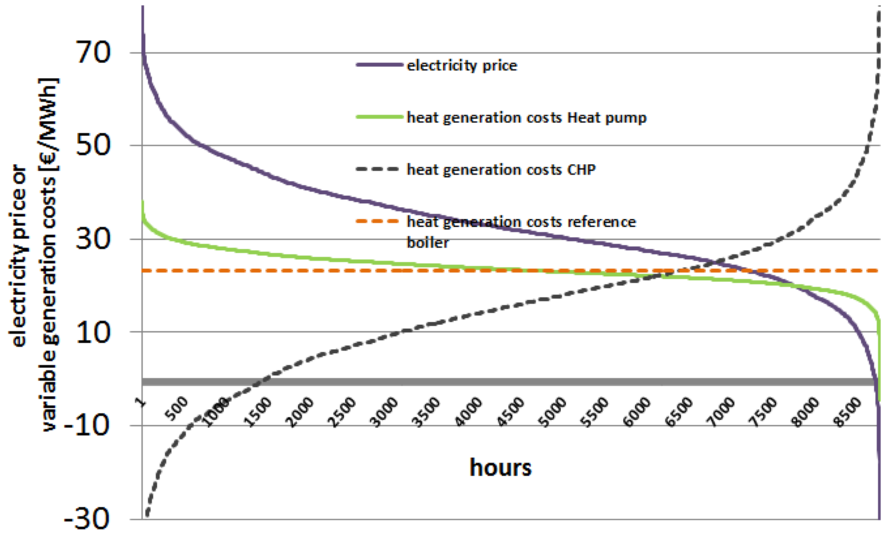
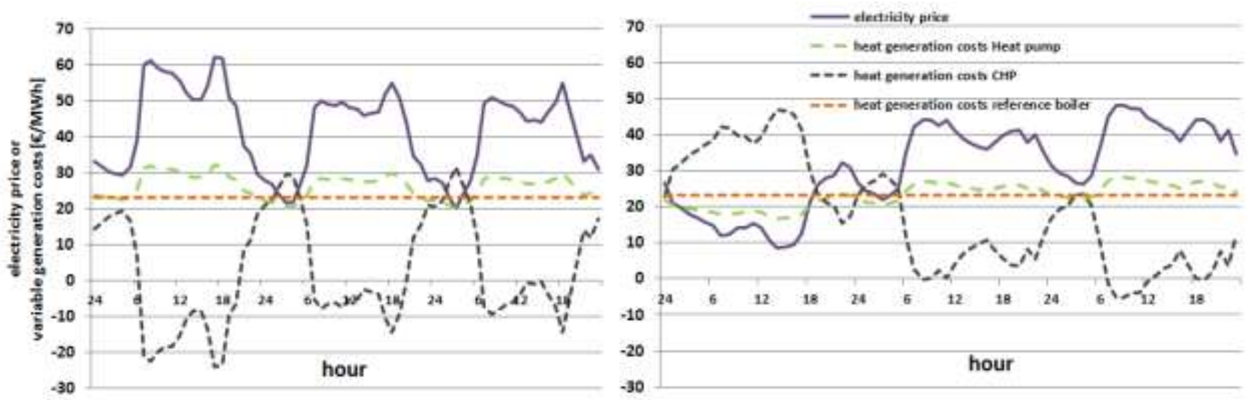


Figure 39 shows the same cost comparison for 3 winter days (left) and 3 summer days (right) for electricity prices in the year 2014. The relationship between the electricity price and generation costs can clearly be seen. The figure also illustrates that due to large price fluctuations on the wholesale electricity markets the heat generation costs of CHPs and heat pumps are variable throughout the day which calls for a flexible operation of the technologies in a heat network.

Figure 39: Short run heat generation costs for a summer and winter week; Source: own calculations



Full cost comparison with reference technology

Note that the previous cost comparison does not include capacity costs. For a full cost comparison those have to be included. As an indicator levelized costs based on annuities of investment costs can be used.

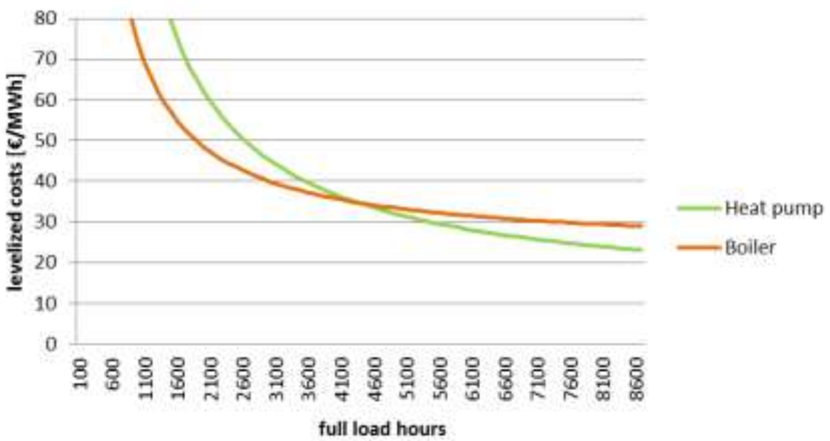
$$p_{el} \cdot \frac{q_{heat\,pump}}{COP} + \frac{CAPEX_{heat\,pump} + OPEX_{heat\,pump}}{T} < p_{fuel\,ref} \cdot \frac{q_{ref}}{\eta_{th\_ref}} + \frac{CAPEX_{ref} + OPEX_{ref}}{T}$$

A comparison with assumption given in Table 13 can be seen in Figure 40. In this example a heat pump would only show lower levelized costs for full load hours (T) above 4 000 h p.a. Note however that this comparison is based on a low and constant electricity price of 40 €/MWh. This does not reflect the variability of electricity prices or any technical restrictions on the output of each technology. It is therefore recommended to use more complex planning tools which allow to account for those variabilities, technical restrictions and the interconnections to other heat supply options when planning the supply of a heat network including CHPs and heat pumps. Please see the following section on heat pumps in portfolio planning.

Table 13: Assumptions for calculation of levelized costs of heat

	invest costs heat pump [€/kW]	discount rate	technical lifetime [a]	O&M [€/kWa]	Fuel price [€/MWh]
Heat pump	900	8%	20	10	40
Boiler	400	8%	20	10	22

Figure 40: Levelized costs of heat over full load hours for heat pumps and boilers, Source: own calculations



Cost saving potential for existing heat networks

From an operator of an existing district heating grid point of view installing an additional heat pump can be seen as a measure to reduce the heat generation costs of the existing supply portfolio. For the heat pump to be profitable, the annual fuel cost savings should therefore be higher than the annual capital costs of a heat pump. This can be expressed by the following equation:

$$\sum_{t=1}^{8760} \max(0, c_{pump,t} - c_{heat\_ref,t}) < CAPEX_{heat\,pump} + OPEX_{heat\,pump}$$

We state the savings as the maximum of 0 and the difference in generation costs between the reference technology (boiler) and the generation costs of a heat pump in each hour as it is assumed that the heat pump would not be operated in hours where the difference is negative. Note that this requirement is much stricter than taking the full costs of other (fossil) fuel generators including their investment costs as a benchmark. At currently low fossil fuel prices and relatively low taxes on natural gas in district heating boilers the annual energy cost savings from installing large scale heat pumps are typically not high enough to offset investment costs. However for rising fuel prices and/or significantly higher taxes on fossil fuel use can be an economical solution in particular if high COPs can be achieved.

Heat pumps in a portfolio decision

The approaches for simple cost comparisons shown above all lack the level of detail necessary to assess the profitability of a heat pump in grids that are exposed to variable electricity prices, variable heat demand throughout the day, seasons and where multiple generation options including heat storage are available. To reflect the complexity of the system and to conduct a robust estimation of the economic potential of heat pumps in a heat network optimization models provide a suitable approach. They allow for the system to be modelled in the necessary level of detail including technical restrictions and hourly variations in demand and supply. For case studies of heating grids in Austria applying such modelling techniques please see e.g. Totschnig et al. (2017). Stochastic modelling approaches also allow for including uncertainties regarding relevant input parameters into the decision-making process (e.g. Rab (2017)).

While there are several ways to model a heat network in optimization the basic problem statement which is presented here is similar in all models:

$$\text{Min} \quad \sum_{j=1}^{J}\sum_{t=1}^{T} q_{j,t}\cdot c\_heat_{j,t} + \sum_{j=1}^{J} CAPEX_j + OPEX_j$$

s.t.

$$\sum_{j=1}^{J} q_{j,t} \geq Heat\_Demand_t$$

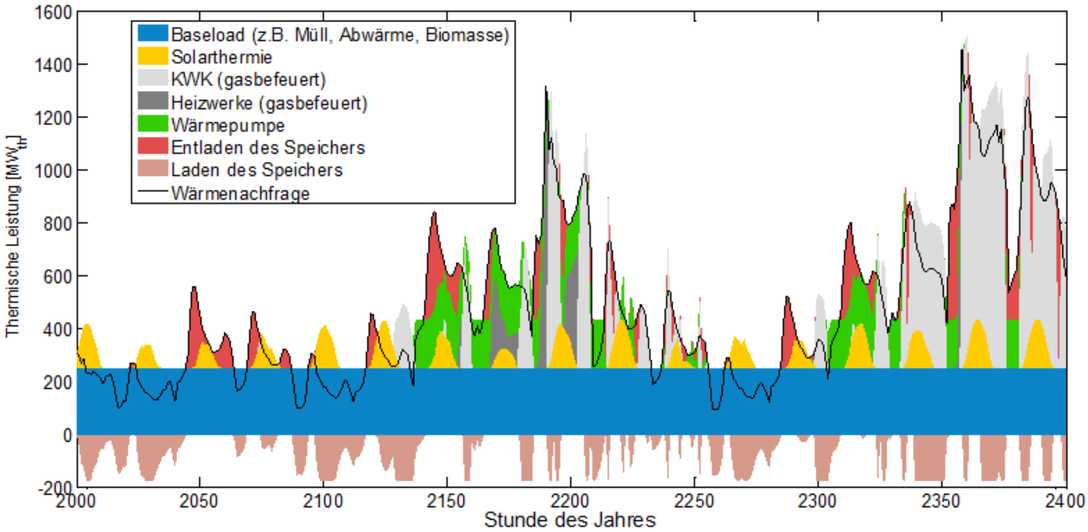
$$\sum_{j=1}^{J} q_{j,t} \leq Q\_max_{j,t}$$

Of course, still the outcome of such optimization models heavily depend on the assumptions on the most relevant input parameters. A general statement on the profitability of heat pumps is not possible without going in detail of each case. However, most model runs are based on current prices or aiming at high decarbonisation of heat supply. The results of these runs show certain trends:

- For high renewable penetration in electricity supply heat pumps become a viable option for district heating grids.
- The flexible operation of all supply options is crucial. Switching between CHPs and heat pumps can happen on a daily basis depending on the situation on the electricity market.
- Heat pumps can also supply additional benefits by providing flexibility and auxiliary services to the electricity grid if they can be operated in a flexible way.
- Back up for high heat loads is still needed irrespective of the installation of heat pumps.
- Stochastic models prefer a combination of all technologies to spread the risks of high or low electricity prices. From this perspective, heat pumps can also be seen as a technology that reduces risks in combination with other technologies. Power 2 heat provides additional flexibility and can provide auxiliary services.

Figure 41 shows an example for the operation of a heat network with multiple flexible generation devices including heat pumps, CHPs, boilers and heat storage.

Figure 41: Example for modelling results of dispatch of heat generation technologies in a large district heating network; Source: own calculations



4.2. Discussion of the market potential for heat pumps in district heating networks

Technical potential

Given the relatively high potential for district heating and already existing infrastructure it can be assumed that the use of heat pumps in district heating will also increase. A major barrier for the use of heat pumps have been the high temperature levels in Austrian heat networks. However, recently new heat pumps have been developed aiming at achieving higher temperatures above 100 °C (see Totschnig et al. (2017)). It should be noted that it is rather unlikely that heat pumps will be installed as a single heat supply option in heating grids. Heat pumps are expected to be operated as additional technologies in existing grids or in combination with boilers or CHPs in new heat networks. Heat pumps could may operate in times of low electricity prices if they are coupled to the balancing market. Totschnig et al. (2017) estimate shares of heat generated from heat pumps in decarbonisation scenarios to be in the range of 10% to 30% of individual heating networks.

Assuming that heat pumps would provide 30% of total heat supply in existing district heating grids this would result in around 6 TWh of heat output assuming the full exploitation of the reduced technical potential for district heating illustrated in section 3.1. Assuming a very ambitious exploitation of district heating potentials in Austria the potential use of heat pumps in district heating grids could be more than 15 TWh annually. Assuming that installed heat pumps would operate at 3 000 full load hours, this would result in installed capacities of 2 GW installed thermal power for a reduced technical district heating scenario and 5 GW for a maximum district heating potential in Austria. With an average COP of 3 this would result in installed electrical power of heat pumps of 0.66 GW_{el} and 1.66 GW_{el} respectively.

The exploitation of the reduced potential of 6 TWh heat delivery by large scale heat pump would result in an additional demand for electricity of around 2 TWh which corresponds to around 2.8% of the current electricity demand in Austria. The maximum electrical power consumption (if all heat pumps operate at full load at the same time) of 0.66 GW_{el} would correspond to around 6% of the current peak load in Austria of around 11 GW_{el}. In combination with power consumption of decentral heat pumps which are increasingly installed in Austria a full exploitation of this potential could put significant additional stress on the electricity supply and security of the electrical grid. It is therefore important that an ambitious roll out of heat pumps in district heating grids is combined with non-electrical back up boilers and the possibility of flexible operation of heat pumps in heat networks.

Electricity market situation

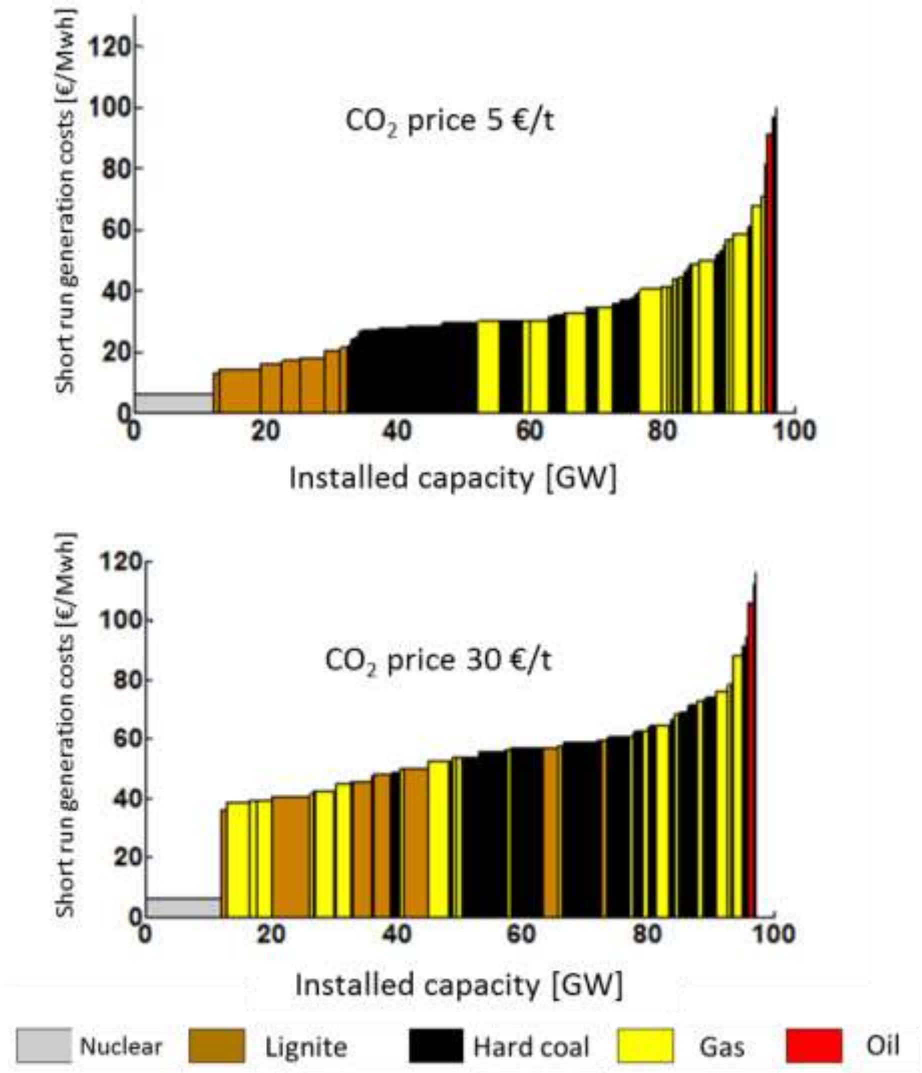
Both the economic potential and the environmental impact of applying large scale heat pumps in district heating networks is closely linked to the electricity system. The current situation with relatively low fossil fuel prices, low CO_2 prices and increasing deployment of renewable energy sources in Austria and Germany lead to low wholesale electricity prices. This makes electrically fuelled heat pumps an attractive generation option for district heating grid operators.

However, it should also be noted that the additional electricity needed to operate heat pumps is currently still produced by power plants based on fossil fuels. Although Austria itself has very high shares of renewables in electricity generation due to high shares of hydro power plants the additional demand for power to heat still triggers additional generation from gas and coal fired power plants given the fact that the electricity market is closely coupled with neighbouring countries with higher shares of fossil fuel generation. Figure 42 shows an approximated merit order of nuclear and fossil fuel power plants in Austria and Germany for CO_2 prices of 5 €/tCO_2 and 30 €/tCO_2. It can be seen that at low CO_2 prices lignite and hard coal power plants show lower marginal costs than gas fired power plants. It can be assumed that at the current situation the use of heat pumps at relatively low wholesale electricity prices will lead to increasing use of coal and lignite fired power plants as even at times of high feed-in from renewables some of those plants are still in operation at the moment.

Figure 42 also reveals that at relatively high CO_2 prices of 30 €/tCO_2 gas fired power plants would be the preferred options which would also lead to less emissions caused by the operation of heat pumps. Note however that lignite plants would still be in a similar marginal cost range as gas fired power plants due to their low marginal fuel costs. Note that of course also higher average electricity prices can be expected when CO_2 prices increase which would also lead to increasing generation costs of heat pumps.

If large-scale heat pumps lead to overall emission reduction in heating and electricity supply as whole strongly depends on the efficiency of heat pumps. Only heat pumps with high COPs will lead to overall emission reductions compared to heat generation with gas or oil-fired boilers. In the medium to long run (provided that the deployment of renewable generation sources continues to increase) the ability of flexible generation within a district heating grid including large scale heat pumps will be increasingly important. If heat generation from electrical heat pumps can be shifted to times of high renewable feed-in where basically all fossil generation has been pushed out of the generation mix, heat generation from heat pumps will also be almost carbon free. However, now this is only the case in a very limited number of hours in the year.

Figure 42: Approximated merit order of conventional electricity generation units in Austria and Germany 2012; Source: own calculations

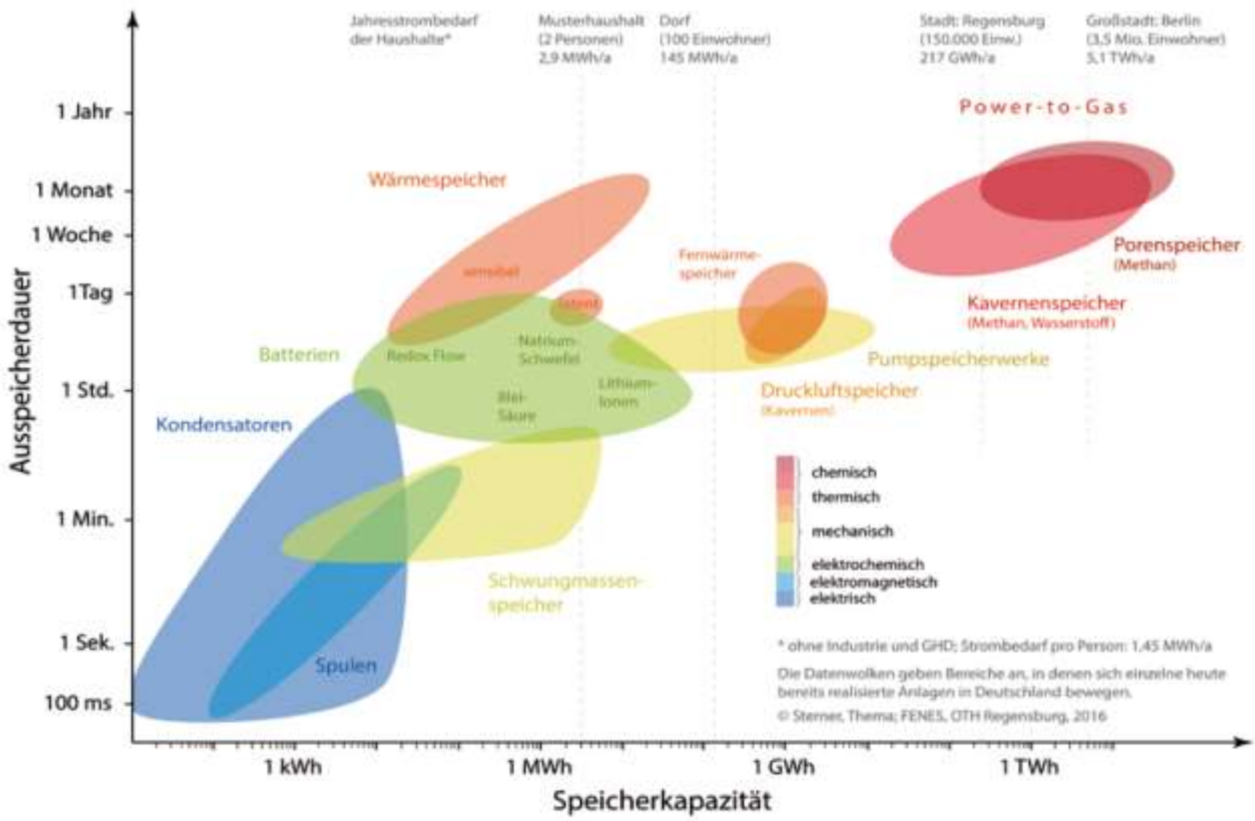


5. Description of thermal storage options

Energy supply and heat demand don't always match regarding place and time; therefore, solutions must be found to eliminate costly capacity. Heat networks must be adapted to the market conditions, to integrate new energy sources into existing systems to allow a sustainable operation of networks. Thermal storage can balance supply and demand allowing a greater role to renewable energy in heating networks.

Large storages in CHP plants at the interface of electricity, gas and heat networks are state of the art and will continue to increase in importance. They are used for short-term energy optimization and load management in heat generation. In the short term, pressure-less storage tanks are mainly used, as these are the most economical storage tanks to date and can be easily integrated into thermal network structures (Klima- und Energiefonds, 2016). Figure 43 provides an overview of different types of storages in various domains including storage capacity (x-axis) and time (y-axis).

Figure 43: Areas of application of storages (Stadler & Sterner, 2017)



5.1. Types of storage systems and integration in heating networks

Seasonal thermal energy storage systems can store heat for several months and thus make energy produced in the summer months usable in winter. Seasonal storage systems are already being used in some pilot plants to supply heating networks with energy. However, the sensitive heat storage technologies currently used have some disadvantages (Köfinger, et al., 2017):

- The capacity of sensitive storage tanks depends primarily on the volume and the temperature difference. Large volumes or high storage temperatures are therefore required.

- In the range above 100 °C, the storage medium water requires increased technical and thus economic expenditure.
- High temperatures lead to increased heat exchange with the environment and thus to high power losses.
- Large-volume storage facilities can lead to massive environmental impact and usually to high investment costs.

The above points show that the seasonal storage of heat is associated with some challenges, which is why technological leaps are necessary here. The integration of innovative (especially thermochemical) storage technologies/materials into heating networks could therefore contribute to improving the energy and economic performance of these systems. These solutions can improve the operation of seasonal thermal storages for thermal networks due to various properties (high energy density, pressure- and lossless storage, easy transportability of materials, etc.).

Heat storage units can be divided into 3 categories:

- <u>sensitive</u>: change their "tangible" temperature during the charging or discharging process
- <u>latent</u>: during the charging or discharging process, the heat storage medium does not change its "tangible" temperature, but rather its physical state. This is usually the transition from solid to liquid (or vice versa). The storage medium can be loaded or unloaded beyond its latent heat capacity, which only then leads to an increase in temperature.
- <u>thermochemical</u>: The energy that is released by binding different molecules, e.g. by sorption, is used here. If, for example, water vapour and a dry, highly porous structure such as silica gel are combined, heat is released due to adsorption effects. The heat is stored by storing both reaction partners separately.

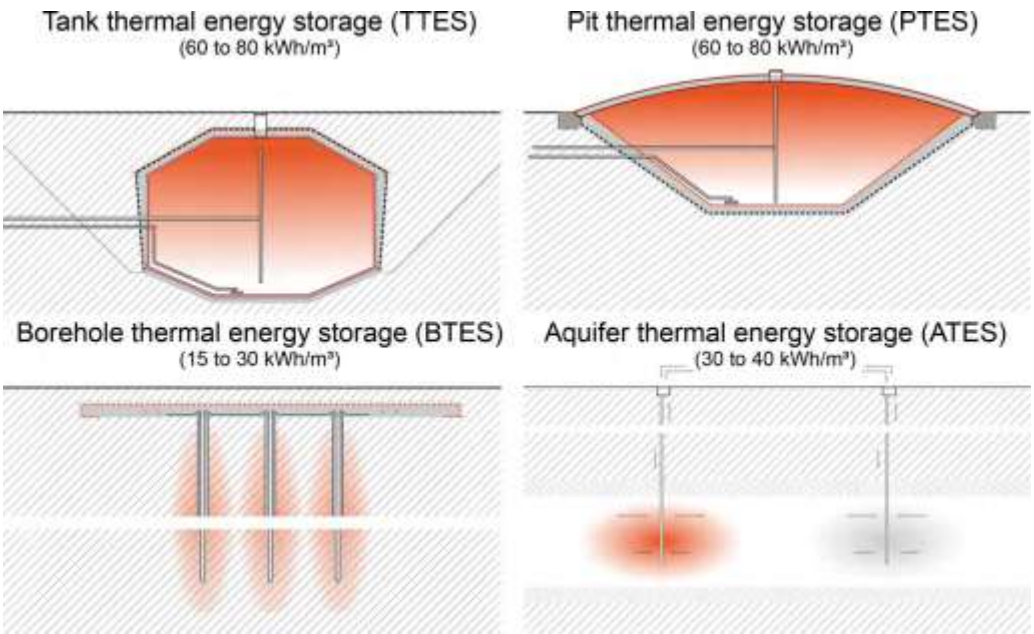
The most common form is sensitive heat storage using water. The potential for reducing peak loads in district heating networks through sensitive short-term storage systems has already been investigated in several studies (Ellehauge 2007; Hoffmann und Puta 2006). This short-term storage of energy favours the integration of renewable energy sources only to a limited extent. To use seasonally fluctuating energies in district heating networks, seasonal thermal storage systems are used in some pilot plants to decouple production and consumption over time (Bauer et al. 2010, S. 612–623; Verda und Colella 2011; Gustafsson und Karlsson 1992). This makes it possible to use the heat gained in summer and winter. In the pilot plants mentioned above, 4 types of large-volume water storage tanks are used to store heat. These are shown in Figure 44. The selection of the storage type depends on the respective geological and hydrogeological situation on site. A previous geological investigation of the subsoil is particularly necessary for aquifer (ATES) and borehole (BTES) reservoirs.

In all these storage tanks, sensitive heat is stored, i.e. energy is stored due to temperature differences. The water in the storage tank is heated (charging) in summer and cooled (discharging) in winter by the district heating network. The higher the temperature of the stored water or the larger the volume, the more energy can be stored. However, due to the high temperatures in the storage tank, the storage medium cools down over time (=heat losses to the environment). It should be noted that the larger the ratio of surface to volume, the greater the specific heat losses to be expected. As the storage tanks are pressure less, the water temperature is limited to a maximum of 100 °C. In practice, these storage tanks operate at around 60 - 80 °C

(Bauer et al. 2010, S. 612–623).

Sensitive storage tanks that operate with water below 100 °C are widespread. Due to their properties (non-toxic, high specific heat, availability, etc.) in various sizes up to several thousand cubic meters are the standard in this temperature range. If temperatures above the range of application of the storage tanks are required, additional heat generators ("boosters" for reheating) must be integrated, for example.

Figure 44: Types of seasonal storages (Schmidt 2014, S. 31)



5.2. Addressing some challenges

Seasonal storages are mainly used in solar district heating (SDH) grids to increase the solar fraction of heat demand. Solar fractions of 50 per cent and more are currently being achieved in Denmark. The largest long-term heat storage facilities are also located in Denmark. One of these is realised in Marstal, which has a volume of 75,000 m³ and is designed as PTES. The maximum usable temperature level is 95 °C, with most storages being charged up to 85 °C in practice. The lower usable temperature range is determined by the return temperature of the connected heat network. In most plants this is at approx. 40 °C. Heat pumps are increasingly being used to improve the management of seasonal storage facilities.

The choice of the appropriate storage concept must be explicitly considered for each system. The local geological conditions, system integration, required storage capacity, performance and temperature levels, number of cycles per year, legal framework conditions must be taken into account. For BTES and ATES, higher official requirements usually apply, especially with regard to water regulations. Ultimately, economic feasibility plays a decisive factor, taking all full costs into account. The choice between tank/pit and borehole/aquifer storage is also strongly influenced by local land prices (SDH solar district heating, 2012). In the system concepts of BTES, buffer storage tanks are usually also provided. This means that the long-term storage can be designed for a heat capacity with an additional degree of freedom (e.g. effect of maximum charging capacities (see also (Riegger, 2008)).

For the implementation, it should be noted that, depending on the type, the seasonal storages could take up two to five years to settle and be fully operational. During this phase, the adjacent soil (especially BTES/ATES) is heated, resulting in higher heat losses (SDH solar district heating, 2012).

5.3. Seasonal storages in Austria

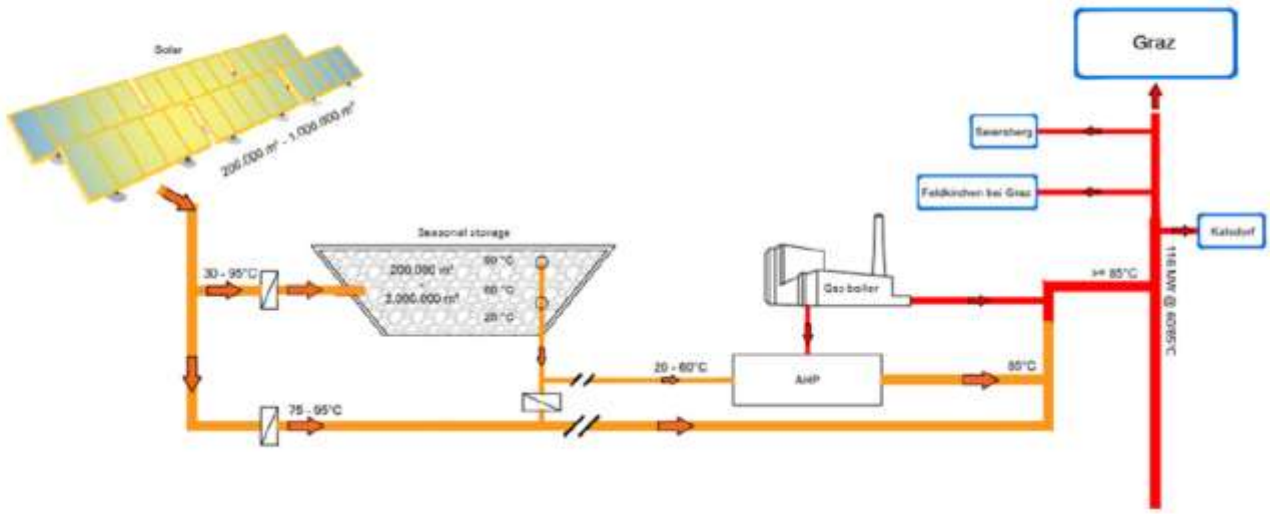
While seasonal storage systems are already being tested and used in district heating networks in Germany (mainly pilot plants) and Denmark (successfully commercial), no such systems have yet been implemented in Austria. Up to now, mainly design studies for the cities of Linz and Graz are available. While a study ("FutureDistrictHeatingGrid Linz" project) is mainly available for Linz, the "BIG SOLAR GRAZ" project in Graz is already a concrete concept whose implementation is being examined in detail.

The inspiration from Denmark made the plans for the BIG SOLAR GRAZ project flourish. According to the motto: *If projects of this kind are profitable in relatively sunny Denmark, why shouldn't they also work economically in far southern Graz?*

Initial calculations for pre-dimensioning based on current load and temperature profiles resulted in a maximum possible solar coverage ratio of just over 30 % (over 300 GWh). To verify this and to obtain a realistic technical-economic optimum, detailed simulation calculations were carried out together with the Danish specialist Planenergi. In a parameter study, a wide variety of variants were tested to achieve an optimum ratio between the costs and benefits of such a large-scale solar system. As an example, the results for a scenario are shown in Figure 45. With the system configuration shown (large coloured figures), more than 240 GWh of solar-thermally generated heat per year contribute to the district heating supply of the city of Graz, which corresponds to around 20 % of the total annual district heating requirement). Of the 240 GWh, 64 GWh can be used directly and 176 GWh are raised to a usable, i.e. higher, temperature level by means of an absorption heat pump.

Despite the great approval of many stakeholders for this project - also and especially from the field of environmental organisations, who see this approach as an exemplary model case throughout Europe - the securing of the necessary plots of land is proving very challenging. In order to finance the approximately 200 million Euros project, a kind of "heat contracting" is currently being discussed with some investors. The final decision on the implementation of the project is expected in 2018, completion is not expected before 2020 (Graf, 2018).

Figure 45: System concept of BIG SOLAR GRAZ (Reiter, Poier, & Holter, 2016)



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