

ESTIMATING UPPER BOUNDARIES FOR GRID CONNECTED SOLAR THERMAL HEAT IN AUSTRIA

Andreas MÜLLER¹, Christian Halmdienst², Richard Heimrath³, Franz Mauthner⁴⁴

Abstract

In this article we estimate the long term potentials for grid connected solar thermal energy potentials at cost optimal solar coverage rates in Austria. This is done in a two-step approach. In a first step we develop long term potential for district heating. This is done by calculating the spatial distribution of energy needs for space heating and domestic hot water production and subsequently defining areas, which could be supplied by district heating. In a second step we perform a techno-economic analysis of the performance of different solar thermal collector field configurations feeding into three different district heating grids.

According to our calculations, district heating could provide about 13 TWh (out of 45 TWh) of energy for space heating and DHW production, considering a reduction of the energy needs by 50% until 2050. Under these settings, heat from grid connected solar thermal collectors could provide about 2.5-3 TWh with solar yields of more than 400 kWh/m² and about 2.6 to 3.3 TWh by considering solar thermal coverage rate at which the lowest solar thermal heat generation costs occur. This potential, however, is quite sensitive to the assumptions on low-cost waste heat. If the waste incineration in Vienna will be operated year-round, the estimated potential is reduced by about 50%.

Keywords: district heating, solar thermal energy, retrofitting buildings, grid connected solar thermal heating

¹⁾ Vienna University of Technology, Energy Economics Group, Gusshausstrasse 25-29, A-1040 Vienna, Austria, Ph.: +43 (0) 1 58801 370362, E-mail: <u>mueller@eeg.tuwien.ac.at</u>, www.eeg.tuwien.ac.at

²⁾ Pink GmbH, Bahnhofstrasse 22, A-8665 Langenwang, Ph.: +43 (0) 3854 3666 60, c.halmdienst@pink.co.at, http://www.pink.co.at

³⁾ TU Graz, Institute of Thermal Engineering, Ph.: +43 (0) 316 873 7317, heimrath@tugraz.at, http://www.iwt.tugraz.at

⁴⁾ AEE - Institute for Sustainable Technologies, Feldgasse 19, A-8200 Gleisdorf, Ph.: +43 (0)3112-5886, f.mauthner@aee.at

1 Introduction

District heating currently supplies more than 20% of the Austrian delivered energy for space heating and domestic hot water purposes. The share has been rising steeply for the past 10-15 years and it is expected that this trend will continue in the next years or decades. Heat from solar thermal collectors represents a carbon-free energy source which can be utilized in district heating networks. While combining district heating and solar thermal collectors is well-established in Denmark, this combination serves only a niche-market in Austria. 24 grid connected solar thermal collector fields with a total collector surface area of about 37 tds. m² were installed in Austria by the end of 2013. The corresponding solar energy yield amounts to 15 GWh/a, or about 0.1 % of the total energy provide by district heating in Austria.

1.1 Research question

In this work we analyze the upper boundaries for the future potential of grid connected solar thermal energy in Austria. This is done by (a) deriving the district heating potential based on costcurves for district heating (DH) infrastructure and (b) estimating the share of energy that could be supplied by solar thermal collectors. The time horizon in focus of this analysis is 2050. The medium to long term potential for district heating are derived by performing a spatial analysis of the energy demand for space heating and domestic hot water supply. While the potential evolution of the decreasing space heating demand is considered explicitly, the industrial and commercial heat demand is not within the scope of the analysis.

The first sub-question has been addressed previously by Amann et al. (2009). In their analysis, they used the energy needs for space heating and domestic hot water demand on 1x1 km grid level, using commercially available data by the Austrian national bureau, to estimate to which the degree a region can be supplied by district heating. In their model, their so called theoretic district heating potential is estimated for three different energy density threshold levels: 4, 6 and 8 GWh/km². Furthermore, an average efficiency increase of 0.75% per year is assumed exogenously. Under their assumptions, this theoretic district heating potential is in the range between 42 TWh, if all areas with an energy density of more than 4 GWh/km² are considered and 30 TWh, if only regions with an energy density of more than 10 GWh/km² are taken into account. By considering additional barriers, they derive their so called realistic potential for district heating, which is in the range of 60 to 65% of their theoretic potential. While this analysis provides a good first estimate of the order of magnitude of potentials for district heating in Austria, the spatial resolution of the 1x1 km grids is not sufficient to perform a sound economic analysis of district heating potentials on a regional level. By using a much finer grid, we try to overcome this short-comes in this work.

2 Methodology

The economics of DH (district heating) are strongly influenced by the ratio of the annual sold energy and the required length of the DH pipelines (linear energy density). To estimate the future upper economic market penetration of DH in Austria, we calculate the energy density for space heating and domestic hot water production nation-wide. Based on the results we identify possible DH areas and calculate the infrastructure costs using an approach developed by Persson and Werner (2011).

To derive the potential techno-economic market penetration of solar thermal energy in DH networks, we deploy a cluster of three models, namely Invert/EE-Lab (Müller, 2015), TRNSYS (TRNSYS, 2014) und SIMPLEX⁵, and calculate the relation between the solar thermal collector efficiency (solar yield) and the energy fraction supplied by solar thermal energy. This is done for three district heating networks. Each network represents an archetype for different district heating cluster, which exists in Austria.

2.1 Spatial distribution of the energy demand for space heating and domestic hot water supply

To estimate the share of buildings, which potentially could be supplied by district heating, we developed a spatially highly disaggregated model for the energy demand for space heating and domestic hot water supply. The data basis for the performed analyses are detailed information on the building stock on the level of municipalities (about 2380 municipalities, based on the definitions in 2001), most importantly the information of buildings by building type, construction period building size (Statistic Austria, 2004a-i), information on the population growth until 2011 (Statistic Austria, 2012) as well as information on number of companies per size and ÖNACE code (Statistic Austria, 2009), which is used to estimate the size of non-residential buildings. Furthermore additional information, namely the number and heated area of residential buildings per size and construction period (Statistic Austria, 2003, 2005-2013), available on the level of federal states are used to estimate the evolution of the building stock for the period of 2001 until 2012. By combining these data we derive a consistent model of the building stock (base year: 2008) on the level of municipals.

In order to derive the energy needs for space heating and domestic hot water production, we deployed the Invert/EE-Lab model (Müller, 2015), a bottom-up simulation model that calculates the

⁵ A bottom-up thermodynamic simulation model for district heating grids developed by one of the authors (Halmdienst) in the course of his master thesis and commercially applied by Pink GmbH for the designing and optimizing district heating networks.

energy needs and energy consumption of buildings based on the monthly semi-steady-state approach as specified by the calculation standards ÖNORM B 8110-6 und ÖNORM H 5056. An additional focus is given on the observed systemic deviations between the calculated theoretical energy needs and the observed values, which allows us to derive energy data which represent the real delivered energy in a better way. The outcomes of the model are by and large consistent the total delivered energy according to the national energy balance on the level of federal states (Statistic Austria, 2014). The deviation between the model results and the national top-down energy balance data are shown in detail in Müller (2015). This model provides, to our knowledge, the only calibrated bottom-up derived energy needs and delivered energy for Austria.

In a second step, we used spatial data for the population density on a 1x1 km grid level (Statistic Austria, 2006) as well as the information, whether or not an area is populated or not (True/False) on the level of a 250x250 meter grid (Statistic Austria, 2008). Based on these data, we generated a generic density distribution model on a 50x50 meter grid. The population density serves as a proxy for the energy demand distribution of residential buildings. For non-residential buildings we assumed that they scale to 70% with the population density, the remaining 30% are uniformly distributed over all populated areas within a given municipality.

The algorithm we applied to generate the density distribution grid, assumes that the density of a given raster point increases with the density of surrounded grid points. An exponentially decay function applied on the distance between two points is used to determine the weight to which degree a point contributes to the density of another point within its neighborhood. We set an upper limit for distance within data points influence each other to 1.04 km. With respect to the different types of buildings (size, construction period, type of usage) within a municipality, we consider them to be uniformly distributed. This assumption allows us to apply the average properties (size, energy demand, etc.) of all buildings within the same municipality on the density distribution function derived in the previous step. The resulting plot ratio – the share between the heated gross floor area within a certain region and the land area – for Austria is shown in figure 1.



Figure 1. Calculated distribution of the plot ratio (floor area ratio) for Austria. Red areas indicate a high plot ratio, while the green color code is used for areas with a low plot ratio.

The plot ratio derived by this approach results for large parts of Austrian in considerable lower plot ratios than studies, which apply a bottom-up settlement types based approach (see e.g. Blesl, 2002; Manderfeld, 2008; Esch 2001). Blesl (2002) distinguishes 14 different settlement types in his work. The type with the lowest plot ratio – low-density residential areas with mainly detached houses with one or two households - considers 766 buildings per square kilometer. By considering the average size of these building categories in Germany, this corresponds to a plot ratio of about 0.1 m² (heated) gross floor area per m² land area. Checks based on randomly chosen villages in Austria using publicly available satellite images confirm that this ratio is also valid for the Austrian situation. Our applied algorithm however, derives for these areas significantly lower plot ratios. The reason for this deviation lies in the fact, that even by considering the information whether or not an area is populated on a 250 meter grid level, we do consider areas as populated or developed, which would not be considered by a settlement archetypes based approach as applied by studies such as Besl (2002). Again based on randomly chosen Austrian villages we estimated that due to this bias, our approach overestimates the populated land area of typical villages with about 1500 to 2000 inhabitants by 40% to 80% and thus underestimates the actual plot ratio by about 30% to 45 %. In order to compensate this effect, we calculated a second plot ratio distribution (which we call "compact settlement structures"), where we reduce the plot ratio of areas with a plot ratio below $0.5 \text{ m}^2/\text{m}^2$ step-wise (three steps) to zero and add their share of buildings to the remaining populated areas within the same municipality. A comparison of the outcome of the two methods with an energy density curve for the total EU28 region (Connolly et al., 2013) is depicted in Figure 2. In Müller et al. (2014), the results are shown and discussed in detail.



Figure 2. Comparison of the calculated energy density for space heating and DHW for Austria with results for the EU28 region, derived by Connolly et al., 2013.

In a next step, we analyze the possible applicability of district heating for contiguous areas. We apply a focal function that combines individual grid points to regions. In order to qualify as a region that, in principle, could be supplied by district heating, a region needs to exceed threshold levels for the total land area, total energy needs for space heating and DHW per region as well as an average plot ratio of the whole region. The result under different assumptions regarding the lower limit of the energy density (energy needs divided by land area) is shown exemplarily for a small region in the south of Vienna in Figure 3.



Figure 3. Spatial analysis on the applicability of district heating considering three different assumptions regarding the lower threshold for the energy density: 20 GWh/km² (left), 10 GWh/km² and 4 GWh/km² (right), exemplarily shown for a ~25x25 km region south of Vienna.

In order to estimate not only the district heating potentials under the current energy needs, we develop three different scenarios for the evolution of the energy needs until 2050. For this analysis we consider the development of the total number of households per region based on projections of Hanika (2011). The resulting energy needs per municipality are then derived by applying the Invert/EE-Lab

model. The energy policy framework conditions are defined in such way, that the final energy consumption for space heating and DHW production of the Austrian building stock decrease by 32%, 42% and 52% until 2050 compared to the consumption in the base year.

2.2 Calculating heat distribution related investment costs of district heating networks

In general, the initial investment costs for district heating grids (capital costs for distribution only) depend on three parameters:

- the annual energy needs per land area,
- o the length of the district heating net per supplied area and
- the specific investment costs for the district heating grid.

To calculate these costs for the district heating regions, as described above, we applied an approach developed Persson und Werner (2010, 2011). In contrast to typical engineering based approaches such as discussed by Blesl (2002) or Esch et al. (2011), their approach doesn't depend on the absolute size of the district heating network. Instead it uses the plot ratio as proxy to estimate typical values for the average diameter of the pipes and other construction related cost parameters. The linear length of the distribution grid per land area is then defined by (Persson und Werner, 2010):

District heating length per land area = 1 / $w = 1 / (61, 8 \cdot e^{-0.15})$ w ... "Effective width" e ... plot ratio

This relationship leads to an annually heat demand per district heating transmission line length ("linear density") of:

Linear density $=Q_s/L = 61, 8 \cdot q \cdot e^{0.85}[GJ / (m \cdot yr)]$ q ... Area-specific heat demand of connected buildings [GJ/m²] Q_s ... Annually sold heat [GJ] L... Length of the heat distribution network [m]

A comparison of the results derived by this approach with available data for 18 district heating grids — six large district heating grids in Austria (Vienna, Graz, Linz, Salzburg, Wels and Villach) as well as 12 smaller district heating networks in Austria and Germany — indicate that this relation seems to valid for the Austrian situation as well (Müller et al., 2014).

The specific construction costs for the district heating grid are defined by a construction costs constant C1 and construction costs coefficient (Persson und Werner, 2011):

 $C = C_1 + C_0 \cdot d_a \quad [\pounds/m]$

The typical construction costs parameters were estimated based on a study of more 1700 city districts in Europe (Table 1), the average pipe diameters are estimated based on the linear heat density model (Persson und Werner, 2011):

$$d_a = 0.0486 * ln(Q_s / L) + 0.0007 [m]$$

 Table 1. Characteristic plot ratio levels and corresponding cost constant and cost coefficient (Source:

 Persson und Werner, 2011)

	Plot ratio e	C1 – Construction cost constant	C2 – Construction cost coefficient			
	[-]	[€/m]	[€/m²]			
Inner city areas	> 0,5	286	2022			
Outer city areas	0,3-0,5	214	1725			
Park areas	< 0,3	151	1378			

The comparison (Müller et al., 2014) of resulting investment costs of this approach with bottom-up engineering-based methods published by Nast (2007) und Manderfeld (2008) indicate a good agreement. Finally, the energy specific capital needs for the heat distribution of district heating networks I_{grid} according to (Persson und Werner, 2011) are defined by:

$$I_{grid} = \frac{\alpha \cdot (C_1 + C_2 \cdot (0.0486 \cdot \ln(Q/L) + 0.0007)}{Q/L} \ [\text{€/GJ}]$$

where Q denotes the total energy sold over the whole considered depreciation period (e.g. 25 years). In this work we extent this model be considering that the heat sold in future periods will decrease due to energy efficiency measures. To do so, we assume that a network is constructed at a given point in time T, and is designed for the heat demand Q_T in T. Heat will be sold starting the following year and the annually sold heat while decline with constant rate.

$$I_{Netz,T} = \frac{C_{1,T} + C_{2,T} \cdot (0.0486 \cdot \ln(Q_T / L) + 0.0007)}{\sum_{t=1}^{\tau} \frac{Q_{T+t}}{(1+r)^t} / L} \quad [€/GJ]$$

$$Q_{T+t} = Q_T \cdot (1-\eta)^t$$
with
$$\tau... \text{ Depreciation time period [yr]}$$
r... Interest rate [1/yr]
$$\eta... \text{ Annual efficiency increase } (\eta = 1.25\% \triangleq -42\% \text{ until } 2050)$$

2.3 Energetic analysis of the integration of solar thermal energy in district heating grids

In this work we link two software packages to analyses the possible integration of heat generated from solar thermal collectors in district heating networks, namely the simplex model and TRNSYS and perform simulations on a sub-hourly resolution. The simplex model calculates the energy flux through the district heating grid. TRNSYS, on the other hand, is used define the energy needs of connected buildings and to simulate the behavior of the solar thermal collectors (TRNSYS Type 832), the heat exchanger between solar thermal collector field, the district heating grid and the heat storage and the heat storage system itself (TRNSYS type 340). The thermal quality of the connected buildings and their evolution until 2050 were taken from the Invert/EE-Lab scenario results. We further only consider the central integration of solar energy into a single knot of the district heating network. The integration strategy furthermore primarily focuses on the integration of the solar energy into the return line of the district heating network.

For the efficiency of the solar collector field, we use characteristic parameters for flat plate, selective solar thermal collector, based on the solar collector database operated by the SPF^6 . The parameters used in this study are depicted in Table 2.

 Table 2. Coefficients of the characteristic efficiency curve of solar thermal collectors applied in this analysis.

η0	a1	a2	(mC)e	kTαd
[-]	[W/m ² K]	[W/m ² K ²]	[J/m²kg]	[-]
0,774	2,887	0,006	7000	0,9

The turn-key investment costs of the solar collector field including a heat storage system of $0.1 \text{ m}^3/\text{m}^2$ collector area are approximated by

$$I_{Turnkey,solar system} = 1122, 5 - 87, 76 \cdot \ln(A_{Apertur}) [\pounds / m_2]$$

As heat storage system we consider a pressureless stratified hot water storage tank, the investment costs are approximated by

$$I_{heat \ storage} = 9136, 8 \cdot V_{heat \ storage}^{-0,497} [\pounds / m^3]$$

A detailed description of the simulation model, the applied parameters and assumptions are given by Müller et al. (2014).

⁶ www.solarenergy.ch

2.4 Analyzed district heating grids

More than 1200 district heating networks are currently operated in Austria. Besides the very large Viennese district heating network, only a few other district heating network can be classified as "large" district heating networks (Graz, Linz, Salzburg, Innsbruck, Dornbirn, Klagenfurt). On the other hand, the very majority of the existing district networks are rural, small-scale district heating networks. An overview of the size and type of the existing networks was performed in the course of the *Solargrids* Project (Müller et al., 2014). This analysis used the qm-Heizwerk database, a database which contains data (with a varying degree of detail) of more than 500 Austrian district heating networks (database status of 2012). The cluster analyses indicated that the networks in the database can be distinguished by the share of customers with a low and high heat demand into the following categories:

• Cluster I, primarily customers with a high heat demand:

More than 75% of the sold heat is demanded by customers with a heat demand of more than 150 MWh/year.

• Cluster II, mixed customer structure:

Customers with an annual heat demand of at least 150 MWh demand less than 75% of the annually sold heat AND customers with an annual heat demand of less than 50 MWh/year demand less than 25% of the annually sold energy.

• Cluster III, primarily customers with a low heat demand:

More than 25% of the sold heat is demanded by customers with a heat demand of less than 50 MWh/year.

Based on the results of this analysis we choose three existing district heating systems, each representing one of the three types described above. For the first cluster (Cluster I) we choose a secondary sub-grid of the Viennese district heating network ("Urban subnet"). The second cluster is represented by district heating network of a small city in Austria (Mürzzuschlag), the third cluster is represented by the district heating network of the small town of Langenwang and is considered to be a typical rural district heating network in Austria. The main parameters for the three district heating clusters and the chosen archetype district heating network are shown in Table 3.

			Nominal						
		Length of	heat				Linear		
	Number of	distribution	demand of	Produced		Network	energy		
	customers	network	consumers	heat	Sold heat	losses	density		
	[#]	[m]	[kW]	[MWh/a]	[MWh/a]	[%]	[kWh/(a [·] m)]		
Cluster I									
Mean Value	67	7444	10123	17402	15038	14	2021		
Median Value	36	4170	5255	8417	7649	9	1743		
Urban sub grid ^{*)}	20	1882	9077	20555	18732	9	10922		
Cluster II									
Mean Value	86	7258	6283	10005	8290	17	1092		
Median Value	56	4833	3591	5211	4236	19	1023		
Small-town district heating grid ^{*)}	232	13230	15650	26750	23241	13	1757		
Cluster III									
Mean Value	74	3852	2580	3894	3130	20	777		
Median Value	57	3282	1763	2581	1986	23	688		
Rural district heating grid ^{*)}	243	12862	4231	9170	6543	29	509		

Table 3. Analysis of district heat networks in Austria and for the archetype district heating networks.

^bData considering an average climate of Austria

3 Results

3.1 Techno-economic long-term potentials for district heating in Austria

In a first step we cluster the Austrian municipalities (Figure 4) according to their annual energy demand for space heating and domestic hot water production into four groups with an almost equally large annual energy demand (the fourth group of municipalities is about 25 % larger than the remaining groups). The first group contains the municipalities with the lowest annual demand. This group contains 1668 (out of 2380) municipalities, the average heat demand of the included municipalities is as low as 14 GWh/year. Based on our calculations (see section 2.1), only 7% of this heat demand can be supplied by district heating. The second cluster contains 535 municipalities with an average annual heat demand of 43 GWh/year. 32% of that heat demand is situated with regions, which classify as suitable for district heating supply. The third group contains of 149 municipalities, 75% of heat demand in this group could be supplied by district heating. The group that contains the municipalities with the largest heat demand contains 28 municipalities; about 95% of that energy demand is considered as suitable for district heating.



Figure 3. Energy demand for space heating and domestic hot water supply in 2008

If we take the expected energy efficiency increase during the next decades into account, the heat densities will decrease strongly, as shown in Figure 4. While the energy demand in regions with a density of less than 6 GWh/km² remains more or less constant (although the area that classifies as such a region increases), the share of high energy density regions decreases dramatically in most municipalities.



Figure 4. Development of energy demand per energy density in the three energy efficiency scenarios

In a next step we calculate the investment costs according to the approach shown above. We further assume that the upper boundary for the district heating potential is defined by the original 250x250 grid approach. The investment costs are assumed to be in-between the original, uncorrected approach and the approach where we correct the plot ratio for undeveloped areas ("compact settlement

structures"). We therefore use the mean value of the investment costs distribution curve as indicator of the subsequent techno-economic analysis. The resulting capital cost curve for district heating networks for Austria is shown in Figure 5. Under current conditions — but already considering the declining energy due to energy efficiency measures — about 40 TWh of heat demand for space heating and domestic hot water supply could be provided by district heating networks at costs for the heating distribution of less than 20 €/MWh. This potential however decreases over time. If we consider the development of new district heating network in scenarios, where the energy needs already declined between 30 and 50%, the district heating potential, again assuming an economic threshold level of 20 €/MWh for the capital costs, declines to 13 to 25 TWh.



Figure 5. District heating networks capital cost - potential - curve for Austria.

3.2 Techno-energetic analysis of the integration of solar thermal energy in district heating networks

We performed the techno-energetic analysis of the integration of solar thermal energy for different types of district heating networks based on the three archetype network described in section 2.4. As it is shown in Table 3, we do not explicitly consider a large urban district heating grid. However, about 50% of the heat distributed by the Viennese district heating system is supplied by about 80 secondary sub-grids such as the one which is used to represents our cluster I, which serves primarily customers with a large heat demand.

3.2.1 Temperature level of supply and return line of the analyzed heating networks

The return and supply line temperature levels in a district heating network have a high impact of the ability to integrate heat from solar thermal collectors. In our case, the design temperature for the supply line in the analyzed urban subnet is 80°C; that of the return line is 55°C. In reality the supply line temperatures are observed to be in the range of 65°C for several months per year, while the return line temperature increase to close to 60°C during the summer period. The two other networks are designed to operate at higher temperature levels. The network representing rural district heating networks with a high share of detached single family buildings (Cluster III, Langenwang) operates with supply line temperatures between 88 °C and 95 °C and an return line temperature between 59 and 65 °C. The third grid, representing a typical heating network of a small Austrian city runs with similar temperature parameters: 83-95°C and 59-62°C. The simplex models of these district heating networks are calibrated based on an observed reference datasets for heat demand, heat supply, heat losses and outdoor temperature. Alternative operation modes such as different outdoor temperatures or a different customer structure have then be simulated. This includes the impact of a decreasing return (and supply line) temperature level due to more energy efficient buildings. In our model, the district heating network needs to provide the temperature level demanded by the individual customers. If the suppled buildings are getting more energy efficient, the heat distribution within the building can be done more easily at lower temperature level. Subsequently, this allows to operate the district heating grid also at somewhat lower temperature level. We therefore assumed that the return line temperature of the analyzed district heating networks will decrease by 7 °C in 2050. More details on our assumption on the relationship between the specific energy needs of buildings, the outdoor temperature and heat distribution temperature within buildings are given and discussed in Müller et al. (2014).

3.2.2 Net solar energy yields and solar coverage

Finally, we analyze the impact of integration a solar thermal collector field on the demanded heat production for the three different heat networks. We perform this analysis for eight different collector fields ranging from 200 to 10000 m² and eight different heat storage tanks in the range between 40 and 2000 m³. We then defined the net solar energy yield as the difference between the demanded heat from the conventional boiler for the situation with the solar collector field as compared to the situation without solar collector. Our results (Figure 6) of the specific net solar energy yields for different collector field and heat storage tank sizes over the solar coverage rate are shown in figure 6. If we consider an optimal combination solar collector and heat storage size, our results indicate that for the rural district heating network and the small-city heating network, a solar energy yield of more than 400 kWh/m² can be reached up to a solar coverage rate of 16 - 17 %. For the third analyzed network, which operates at lower temperature level, such energy yields can be achieved until a solar coverage rate of about 19%.



Figure 6. Specific solar energy yields for different combinations of solar collector field and heat storage sizes and district heating networks.

3.2.3 The economics of the integration of solar thermal heat in district heating networks

By considering the initial investment costs of the solar thermal collector field, the additional heat storage system, additional pipes, heat exchangers as well as control and regulation systems, we can calculate the specific (net) heat generation costs of the solar thermal energy feed into the grid. This is been done, using the capital cost curves shown above. We further consider an interest rate of 6% and an economic depreciation time of 20 year; parameters which lead to an annuity factor of 0.09. Under these economic assumptions we get solar thermal heat generation costs in the range of 65–85 ϵ /MWh (Figure 7). For the analyzed rural district heating network we receive the highest costs; the cost optimum occurs at a solar coverage rate between 10 and 15%. For the district heating network of Mürzzuschlag (Cluster II), the cost optimum is found at a solar coverage rate between 20 and 25%.



Figure 7. Specific solar heat generation cost considering an annuity factor of 0.09.

3.2.4 Impact of increasing building efficiency on the integration of solar thermal heat in district heating networks

Retrofitting buildings mainly reduces the heat demand during the heating season and thus increase the relative share of energy that is demand during the summer period. The impact on the solar energy heat generation costs is shown in Figure 8, exemplarily for the urban secondary sub grid. According to our analysis, heat generation costs do not decrease significantly if capital costs remain on the same level. The cost optimal configuration however shifts towards higher solar coverage rates. In the shown example the cost optimal configuration (considering a solar storage tank volume of 2000 m³) occurs at a solar coverage rate of 31% under the -40% energy demand conditions, while under the load profile of the 2010 building stock this optimum already occurrs at a solar coverage rate of 19%.



Figure 8. Impact of retrofitting buildings on the solar heat generations cost (annuity factor = 0.09)

3.3 Potentials for grid connected solar thermal energy in Austria

The techno-economic analyses shown above indicate that under current energy prices and technology costs, solar thermal is not economically completive without financial support. In order to move from its current niche market towards a well-established mass market product, either solar system cost reduction need to be achieved, or energy policy measures which to some degree support the installation of solar thermal collectors, need to be in place. Regarding the systems cost reductions, recent market development indicate that investment costs could decrease significantly within the next few years and move towards system costs as being observed in Denmark already for several years. An example for an energy policy measure that supports the integration of solar thermal energy is the calculation procedure according the qm-Heizwerk standards, which defines how the total annual energy utilization indicator has to be derived. In order to receive investment fundings for the extension or construction of (biomass fueled) district heating networks, this energy utilization indicator needs to exceef certain threshold levels. Since on-site renewables are not counted as an energy input by this calculation procedure, the utilization of solar thermal energy can help to surpass the demand threshold level.

In contrast to the economic potentials under current cost assumptions, from a technical point of view, and considering sufficient large seasonal heat storage systems, very high solar coverage rate could be achieved. In order to define useful potentials for grid connected solar thermal energy utilization, we therefore consider the share of solar thermal energy where the cost minimum occurs as the boundary for the upper potential.

Currently, this cost optimum occurs — depending on the district heating network type — at solar coverage rates between 12 and 22%. If we further consider the effects that arise from retrofitting the building stock, this optimum shifts to higher solar coverage rates. In average, a cost optimum at a solar coverage rate of 25% appears to be realistic. If we further consider a district heating potential of about 13 TWh/a in a scenario where the heat demand decreases by 50% until 2050, we receive a grid connected solar thermal energy potential in the range of 2600 - 3300 GWh/a for Austria.

4 Conclusions

Our results indicate that under current conditions, about 40 TWh of energy for space heating and domestic hot water production could be served by district heating with grid costs of less than $20 \notin$ /MWh. If we take a future reduction of the energy needs for space heating and domestic hot water of 50% into account, this potential shrinks by about 65%. About 80% of the remaining potential is demanded in 9 Austrian cities. If we neglect competing low-cost production technologies during the summer season, in such a scenario, about 2.5 – 3 TWh/a could be supplied by solar thermal collectors with an energy yield of more than 400 kWh/m². This potential, however, is quite sensitive to the assumptions on the availability and utilization of low-cost waste heat. If the waste incineration in Vienna will be operated year-round, the estimated potential is reduced by about 50%.

Acknowledgements

The analyses shown and discussed in this article were supported by the Austrian the Climate and Energy Fund and performed in the course of research project "Solarenergie und Wärmenetze: Optionen und Barrieren in einer langfristigen, integrativen Sichtweise".

5 References

Amann, C., Benke, G., Leutgöb, K., 2009. Entwicklungspotenziale für Fernwärme und Fernkälte in Österreich, e7 Energie Markt Analyse GmbH.

Blesl, 2002. Räumlich hoch aufgelöste Modellierung leitungsgebundener Energieversorgungssysteme zur Deckung des Niedertemperaturwärmebedarfs, Dissertation an der Universität Stuttgart, Institut für Energiewirtschaft und Rationelle Energieanwendung, 2002. ISSN 0938-1228

Connolly D., Mathiesen B.V., Østergaard P.A., Möller B., Nielsen S., Lund H., Persson W., Werner S., Grözinger J., Boermans T., Bosquet M., Trier D., 2013. HEAT ROADMAP EUROPE 2050, SECOND PRE-STUDY FOR THE EU27, Aalborg University, Denmark, 2013. ISBN: 978-87-91404-48-1.

Esch T., Taubenböck H., Geiß C., Schillings C., Nast M., Metz A., Heldens W., Keil M., 2001. Potenzialanalyse zum Aufbau von Wärmenetzen unter Auswertung siedlungsstruktureller Merkmale. Technical report, Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gesellschaft, Oberpfaffenhofen, Deutschland, 2011.

Manderfeld M., 2008. Handbuch zur Entscheidungsunterstützung – Fernwärme in der Fläche. Dinslaken, 2008.

Hanika, A., 2011. Kleinräumige Bevölkerungsprognose für Österreich 2010 bis 2030 mit Ausblick bis 2050 ("ÖROK - Regionalprognosen") / Teil 3: Modellrechnungen zur regionalen Haushaltsentwicklung. ÖROK-Schriftenreihe 184/2011.

Müller, A., Büchele, R., Kranzl, L., Totschnig, G., Mauthner, F., Heimrath, R., Halmdienst, C., 2014. Solarenergie und Wärmenetze: Optionen und Barrieren in einer langfristigen, integrativen Sichtweise, Technical report.

Müller, A., 2015. Energy Demand Assessment for Space Conditioning and Domestic Hot Water: A Case Study for the Austrian Building Stock (PhD-Thesis). Technische Universität Wien.

Nast, M., 2007. Nahwärme: Der Missing Link zwischen kleiner KWK, Erneuerbarer Energie und Wärmeverbrauchern, Presentation at the BMU-Workshop "Perspektiven der Brennstoffzelle", Berlin, 14.3.2007.

ÖNORM B 8110-6, 2007. Wärmeschutz im Hochbau – Teil 6: Grundlagen und Nachweisverfahren – Heizwärmebedarf und Kühlbedarf. ÖNORM B 8110-6:2007-08-01. Austrian Standards Institute, Vienna.

ÖNORM H 5056, 2007 (Pre norm). Gesamtenergieeffizienz von Gebäuden – Heiztechnik-Energiebedarf. ÖNORM H 5056: 2007-08-01. Austrian Standards Institute, Vienna.

Persson, U. and Werner, S., 2010. Effective width – the relative demand for district heating pip lengths in city areas, The 12th International Symposium on District Heating and Cooling, September 5th to September 7th, 2010, Tallinn, Estonia.

Persson, U. and Werner, S., 2011. Heat distribution and the future competitiveness of district heating, Applied Energy, Volume 88, Issue 3, March 2011, Pages 568–576.

Statistic Austria, 2003, 2005-2013. Annual publication series: "Wohnen, Ergebnisse der Wohnungserhebung im Mikrozensus Jahresdurchschnitt. Statistik Austria, Vienna. ISBN 3-901400-90-7 / 3-902479-44-2 / 3-902479-71-X / 978-3-902587-28-2 / 9 78-3-902587-61-9 / 978-3-902703-10-1 / 978-3-902703-45-3 / 978-3-902703-93-4 / 978-3-902791-40-5 / 978-3-902791-89-4

Statistic Austria, 2004a-i. Gebäude- und Wohnungszählung 2001, Statistik Austria, Vienna. ISBN: 3-902452-72-2 / 3-902452-73-0 / 3-902452-84-6 / 3-902452-85-4 / 3-902452-86-2 / 3-902452-92-7 / 3-902452-93-5 / 3-902452-94-3 / 3 -902452-95-1

Statistik Austria, 2006. Population 2006 ETRS-LAEA 1km. Statistik Austria, Vienna.

Statistic Austria, 2008. Siedlungsraum und besiedelbarer Raum (= Dauersiedlungsraum). Statistik Austria, Vienna. <u>http://www.statistik.at/web_de/klassifikationen/regionale_gliederungen/</u> dauersiedlungsraum/index.html (last access: March, 2015)

Statistic Austria, 2009. Blick auf die Gemeinde, Merkmal: Arbeitsstättenzählung vom 15. Mai 2001. Statistic Austria, Vienna. http://www.statistik.at/blickgem/index.jsp (Zugriff: März, 2015)

Statistic Austria, 2012. Blick auf die Gemeinde: Merkmal: G2.1 Bevölkerungsentwicklung. http://www.statistik.at/blickgem/index.jsp (last access: June, 2012)

Statistic Austria, 2014. Gesamtenergiebilanz Österreich 1970 bis 2013 (Detailinformation). Statistik Austria, Vienna. Retrieved from <u>http://www.statistik.at/web_de/static/gesamtenergiebilanz</u> <u>oesterreich_1970_bis_2013_detailinformation_029955.xlsx</u> (last access: March, 2015)