Task 55 Towards the Integration of Large SHC Systems into DHC Networks

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

The future of DH and the role of solar thermal energy

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Summary

Solar thermal (ST) energy is one of the few renewable heat sources that is available almost everywhere and can bring multiple benefits to district heating and cooling (DHC) networks (on an environmental and systemic level) with very low operation costs and risks. However, the current share of ST in DHC networks is almost zero on a global scale.

The international cooperation between IEA SHC Task 55 Subtask A, SHC Task 52 and the IEA DHC TCP (especially Annex TS2) gave important insides into the possible role of solar thermal energy in district heating networks on a national scale and possible transformation strategies of district heating and cooling networks towards a high solar share.

Introduction

An important backbone of the heat sector is represented by district heating (DH) and district heating and cooling (DHC) networks. In fact, worldwide, there are more than 80.000 and in Europe there are more than

6,000 DHC systems in operation (only counting cities with more than 5,000 inhabitants) accounting for 11% of the global heat supply [1]. However, the current status of DHC indicates a still dominating presence of fossil fuels, see Figure 1. Biofuels and waste are the only remarkable renewable energy source and they play a minor role on a worldwide level and have some more significant share in Europe. In this context, solar thermal (ST) contributes globally to less than 0.01% of the heat production for DH [2]. However, the presence of ST-supported DHC networks is highly diverse across countries. For example, well-known is the very high penetration in Danish DH, with more than 1 million m^2 operating collectors, and additional 430 000 m^2 planned, and a further increasing trend of both solar installations and seasonal thermal storage systems.

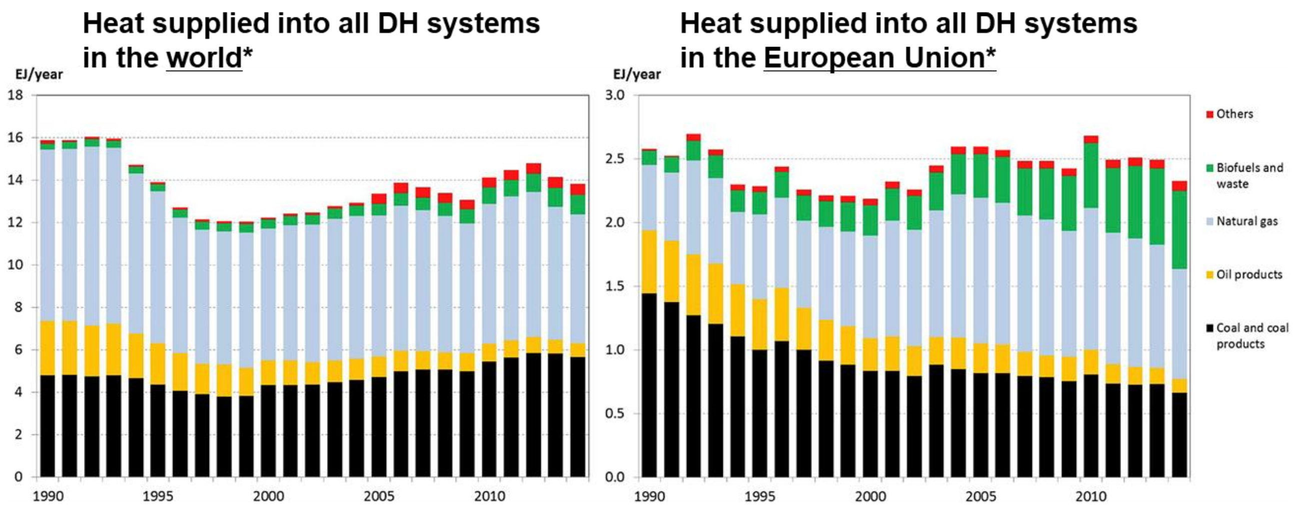

*Figure 1 Heat supplied into all DH systems in Europe and in the World (*according to original energy supply sources used) [1]*

The majority of energy supply to DHC networks is based on combines heat and power (CHP) plants. However, the role of CHP plants will significantly change in the future since

A) decarbonisation will make the use of fossil fuels impossible, and
B) for renewable fuels such as green hydrogen (H2) or biomethane, there will be a growing competition with hard-to-decarbonise sectors such as air transport and certain industrial processes. Further on,
C) an increasing share of renewable electricity production from hydro, wind and photovoltaics (PV) will drastically reduce the amount of electricity produced from CHP plants.

Although the specific heating demand in DHC networks might decrease due to by trend milder winters and an increasing energy efficiency of the buildings, many DHC networks are densifying and expanding their customer base, thus expect to keep their absolute heating demand stable. Further on, many regions in the world still have the economic potential for installing new DHC networks. Consequently, other heat (and cold) sources will be needed for covering the heat (and cold) demand in DHC networks in the future[1] - and together with this ~~sutiable~~ decarbonization strategies towards low-carbon systems.

[1] Including waste heat from industrial processes, the service sector (e.g. data centres) and urban infrastructures (e.g. sewage channels), ambient heat (e.g. ~~ground water),~~ solar thermal and geothermal energy

In recent years, megawatt-scale ST systems supplying DHC networks have gained increasing attention. A simulation study for Austria, Denmark, Germany and Italy estimated a technical potential between 3% and 12% ST share in 2050 (*ST share = heat supplied by ST collectors / overall heat supply to the end customers*) [3]. However, besides several advantages, the integration of large ST systems into existing and new DH networks faces several challenges. Within the IEA SHC Task 55, a SWOT analysis has been performed for SDH, see Figure 2.

	POSITIVE	***NEGATIVE***
INTERNAL FACTORS	***Strengths*** 1. Very low operating costs 2. Emission free (CO_2, NO_x, noise) 3. Low investment risk	***Weaknesses*** 1. High specific CAPEX, reflecting in long payback times 2. Suitable areas for ST installations are limited in cities 3. Summer competition/ TES are needed to meet high ST share → increased investment and land usage
EXTERNAL FACTORS	***Opportunities*** 1. Increasing need for reducing CO_2 and increasing subsidies for renewables 2. biomass is more suited to high-temperature applications, mobility etc. 3. The investment costs can potentially decrease when the market increases	***Threats*** 1. The long payback times reduce flexibility and chance 2. Little public awareness of ST, lack of marketing, difficult to understand for decision makers 3. Electricity (power-to-heat) becomes cheaper and cheaper

Figure 2 ***SWOT analysis**** *of solar thermal integration in DH networks [4]*

Example Austria

Austrian DH has experienced a fast increasing trend for the last 30 years (with the exception of the period 2010-2014), resulting in a triplication of delivered heat [5]; in the year 2018, with about 2400 networks and 20 TWh supply, DH covered 6.4% of the final energy consumption (1122.5 PJ) [6]. Currently, district heating provides about 26% of the Austrian households with the energy requested for space heating and domestic hot water preparation [5]. Regarding DH, the most important heat sources are biofuels (47%) and gas (36%), followed by municipal waste (7%), oil (5%), and coal (5%). Almost 60% of the heat is produced in CHP units, while the remaining part is produced in heat-only boilers. ST plays such a marginal role that it is not even mentioned in some official studies. However, at least 60 000 m^2 collectors were installed in 102 DH systems between 2010 and 2016. Significant success stories are for example the one of Lehen (urban district of Salzburg), with 2047 m^2 flat-plate collectors showing a year solar yield of 533 kWh/m^2_{ap} and 35% ST fraction, and the one of Fernheizwerk Graz, which with 7700 m^2 represents the largest SDH system in Austria. The possibility of an increasing trend in Austria appears quite realistic in consideration of the important role that ST has gained in other countries as well as of Austrian decarbonization targets.

Solar district heating perspectives in Austria - scenarios for 2030

AIT assessed the optimal share of ST in Austrian DH in 2030 by means of Balmorel, an open-source bottom-up modelling tool based on partial equilibrium optimization and calculating the optimal dispatch and investment on different generation technologies in electricity and DH [7]. The results of the model include the economically efficient dispatch of electricity generation technologies and optimal investment in generation and transmission capacity based on different future energy scenarios. Figure 3. shows a comparison between the share of different DH generation technologies in 2030 (model results) with the current DH generation portfolio in 2018. The results indicate an increase of ST production from almost zero in 2018 up to 3.8% of total DH generation in 2030. Besides, the production from heat pumps in Austrian DH will increase ~~up~~ 23.5% of total DH generation in 2030. On the other side, the share of natural gas in DH generation will drop from 37% in 2018 to 22% in 2030. The generation from oil and coal fuels will drop to zero in 2030, as the generation from these sources will not be economical anymore.

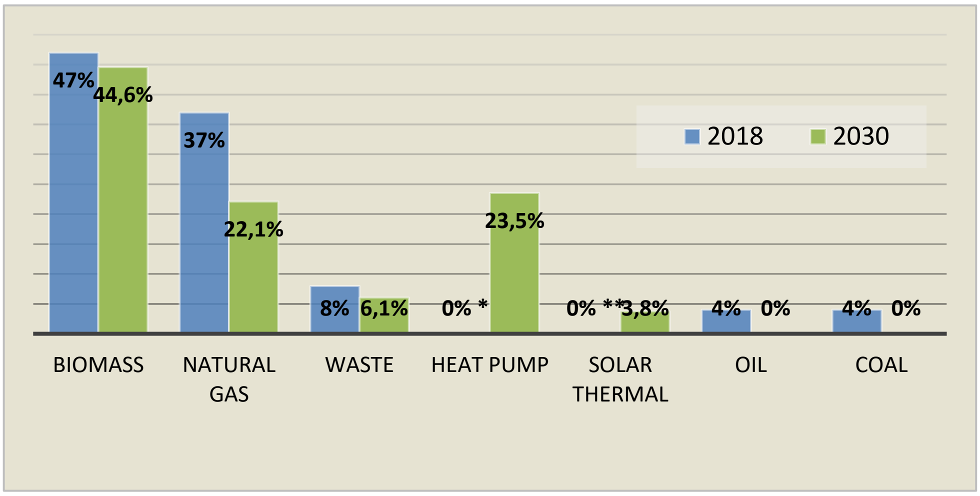

Figure 3. District heating generation in Austria (2018 vs 2030)

Big Solar Graz

A very ambitious example of a transformation strategy involving a very high proportion of renewable energy sources is the Graz heat network. Due to the uncertain future of the most important CHP plant, various alternative generation options have been developed since 2013 in addition to various efficiency measures, some of which have already been implemented [8]. Fig. 1, left illustrates that current energy generation for DH, is primarily based on waste heat from fossil-fired CHP plants. One of the projects for increasing the share of renewables is "BIG Solar Graz" which is supposed to have a share of about 20% on the overall DH supply in Graz – see Fig. 1 right.

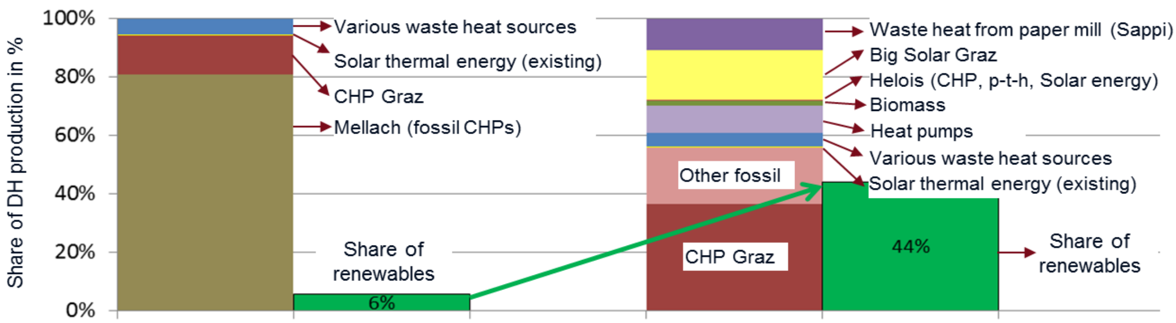

Figure 4.: Transformation strategies, example: Graz, left: current situation of the DH network in Graz, right: possible future supply mix (Prutsch 2017, translated, p-t-h = power-to-heat)

Methodical approach for developing transformation strategies

Many district heating networks have historically evolved structures whose transformation is subject to various boundary conditions (technical, regulatory) and influencing parameters (energy market and customers). Furthermore, different decision criteria (economic, ecological) and stakeholders (network operators, customers, city, and country level) must be taken into account. Accordingly, decision making for new generation technologies is very complex and requires a transparent and consistent approach. In this section, a method is presented that allows a clearly structured decision making process and is divided into the following three phases, see Figure 5

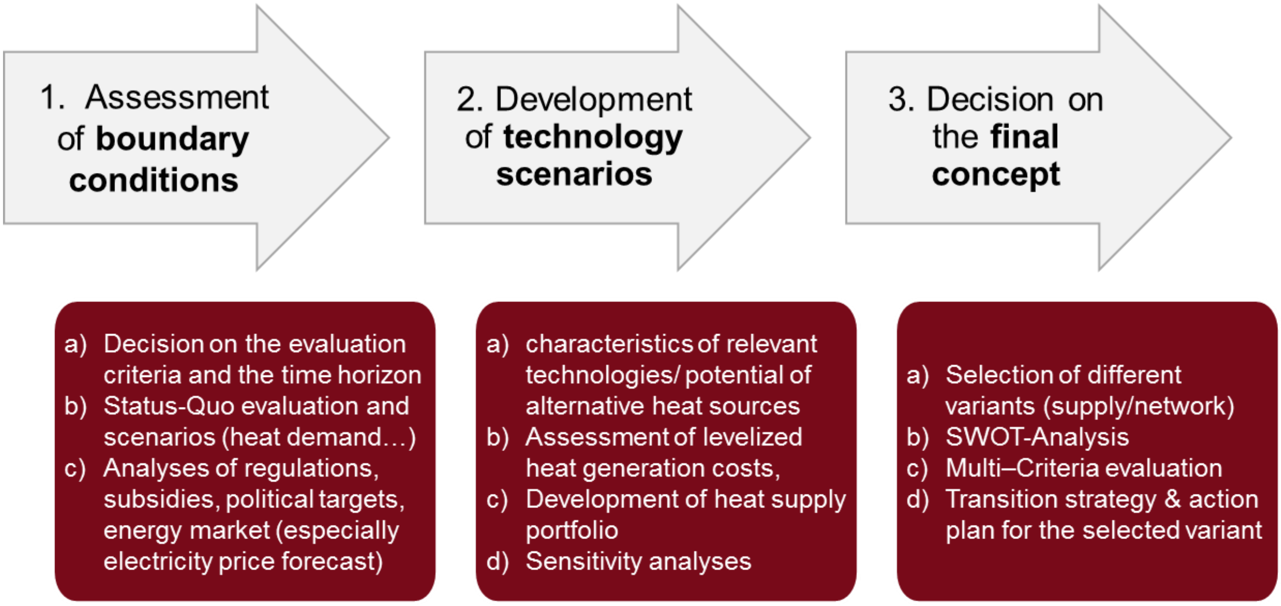

Figure 5. - Methodological overview for developing transformation strategies

Analysis of the boundary conditions

The first phase creates the basis for further considerations in phases 2 and 3 and includes:

<u>a) Coordination of the evaluation criteria and the time horizon:</u> The essential evaluation criteria are discussed and defined with the involvement of the main stakeholders, including the time horizon of the scenarios and target values for the evaluation criteria.

<u>b) Status quo evaluation and scenarios:</u> The existing heat generation plants as well as the grid infrastructure will be evaluated, as well as scenarios for the development of the heat demand need to be prepared. In addition, an estimate should be made of the reduction in network temperatures, as an important prerequisite for the increased use of alternative heat sources [9].

<u>c) Analysis of the energy and climate policy framework:</u> The most important focus is on electricity and fuel price developments (biomass, natural gas) for the evaluation of CHP plants and power-to-heat applications, i.e. the estimation of the hourly profiles.

Development of technology scenarios

In the second phase, different technology scenarios or producer portfolios will be developed as the basis for decision-making in phase 3. This includes:

a) Characteristics of the generation plants/potentials of alternative heat sources: In this step, the techno-economic characteristics of relevant generation plants are evaluated. Furthermore, it is important to estimate the available or technical potential of the relevant heat sources, in particular:

- *Biomass and municipal waste*: The medium- and long-term availability within the city or its immediate surroundings.
- *Solar thermal energy*: including roof areas and open space. Furthermore, the local irradiation characteristics and ownership conditions must be taken into account.
- *Deep geothermal energy*: The hydrogeological prerequisites for the use of geothermal energy vary greatly from region to region, so that the available potentials must be determined. However, the potential cannot always be predicted precisely and that the technical expenditure for drilling is high resulting in a high risk.
- *Waste heat*: The producing sector (e.g. steel and cement works) and the service sector (e.g. data centres ...) are possible candidates. The potential can be determined either with the help of available waste heat atlases, see e.g. (Büchele, et al., 2015) or via key figures, see e.g. (Loibl, Stollnberger, & Österreicher, 2017). In the case of low-temperature sources, however, heat pumps are required for utilization.
- *Heat pumps*: Besides industrial waste heat (see above), waste heat from sewers or sewage treatment plants (see e.g. Ochsner, 2013) and waste heat from sea or river water (see e.g. Wilk, Windholz, Hartl, & Fleckl, 2015) are particularly relevant heat sources. Furthermore, waste heat from the power plant process itself can be used, e.g. from flue gas condensation, e.g. (Fleckl, et al., 2014) or cooling water, e.g. (Wien Energie, 2017).

b) Calculation of heat production costs: Using the data developed in step 1, the heat production costs of the relevant generation technologies and heat sources from step 2 a) are determined as a function of the full load hours, providing the input data for step 2c).

c) Development of producer portfolios: In order to reduce the number of possible variants, a preliminary selection of the generation plants is made based on the annual duration line of the consumers and the economic and technical boundary conditions from the previous step (Figure 3).

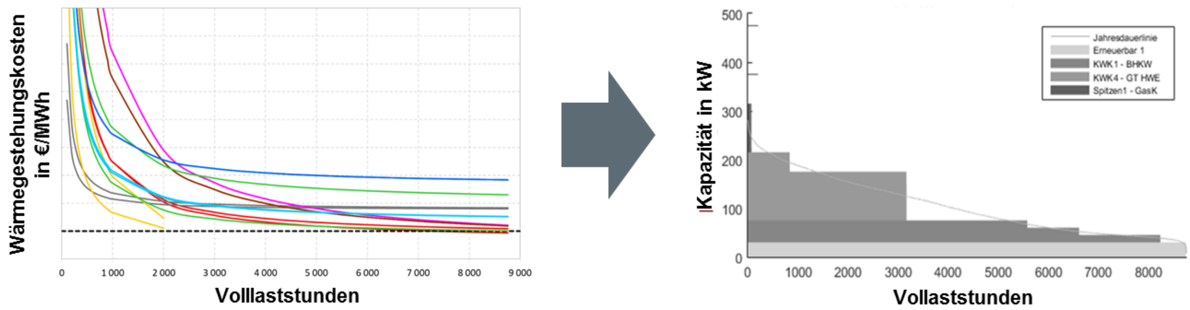

Figure 6. - left: Full load hours of the relevant generation technologies depending on the heat production costs, right: Use of an optimization tool (here VarOpt VarOpt2)) to create producer portfolios.

d) Sensitivity analysis: Based on the rough selection and dimensioning in step 2c) a sensitivity analysis for different external boundary conditions from phase 1 (especially electricity and fuel prices as well as heat demand) is performed. Since for the optimal use of CHP and power-to-heat plants it is necessary to consider the hourly electricity price curves, the sensitivity analysis uses an application and operation optimization. A number of optimisation programmes exist for this purpose, which consider factors such as fuel, start-up and

[2] Own development AIT/ TU Wien

maintenance costs, CO2 certificates and the electricity remuneration of CHP plants, and which make application forecasts on the basis of consumption and weather data, see e.g. (procom, 2017), (TU Dresden, 2009). This also applies to the decision to load and unload storage facilities.

Decision on the final concept

The final concept development in phase 3 summarizes the results of phase 2 and compares all scenarios. This includes:

a) Selection of different variants (generation/grid) The first step is the development of ~~meaningfull~~ combinations of generation and, if necessary, heat grid options for heat supply variants. Attention must be paid to the compatibility of the options, e.g. island grid solutions can only be realised with smaller, modular generation plants or, in the case of decentralised feed-in, the grid hydraulics must be checked and, if necessary, expansion measures taken into account.

b) SWOT analysis The SWOT analysis is carried out as part of strategy development to support the quantitative evaluation of the various supply variants. Instead of carrying out an individual SWOT analysis for each individual supply option, it makes more sense to carry out the SWOT analysis for the relevant generation technologies or supply options themselves.

c) Multi-criteria evaluation. A standardized, weighted decision matrix of all meaningful variants or generation portfolios is used for the final decision making. Where possible, the individual portfolios are evaluated on the basis of quantitative data from step 2d) - which is particularly possible for the economic and ecological parameters - and on the results of the SWOT analysis from step 3a) - for the technical and other criteria. The criteria are weighted against each other and the respective sub-criteria against each other in accordance with step 1a) in order to obtain a clear ranking of the different variants. In this way, the preferred variant is selected with the relevant stakeholders and, if necessary, specified for the next step.

d) Transition scenarios and action plan for the selected variant. For the preferred variants, the necessary implementation measures (detailed studies, permits, tendering procedures, etc.) and a sensible timetable for the transformation of existing plants and the installation of new plants were derived. In addition to the minimum capacity required to cover the heat demand scenarios, this plan also took into account n-1 reliability and the remaining service life of the existing plants or any subsidies.

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