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BIG Solar Graz: Results of a techno-economic feasibility study

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Abstract

Current heat generation for district heating (DH) in Graz, Austria is primarily from waste heat of fossil-fired combined heat and power (CHP) plants. Due to low prices on the European electricity market, the operation of CHP plants is not economic sound anymore and may lead to problems for cities, that are highly dependent on the heat of such plants. The operator of the CHP plants in Graz recently announced their closure in 2020. Almost 80% of the overall heat production has to be replaced.

The research focus of this paper is to analyze the technical and economic potential of integrating a centralized large-scale solar thermal system including seasonal pit storage and absorption heat pumps for DH. Therefore, the purpose of the research is to determine the techno-economic optimum size of such a solar system, that can be integrated into the district heating system of Graz. The study includes the design of a technical concept using dynamic simulation, an investigation of appropriate land for collectors and the storage and an economic cost evaluation of its realization.

First results indicate a techno-economic optimum of the system of 450,000 m² providing 20% solar fraction of the overall heat demand. Especially, the use of a series of absorption heat pumps with a total capacity of 100 MW is a key element in the system in order to accelerate the cooling down process of the seasonal pit storage and enables a higher solar fraction.

There is a high potential of integrating such a large-scale solar system in the DH net of Graz. Considering the framework conditions such as grid temperatures and waste heat potentials the BIG Solar Graz concept is applicable to other cities with DH and may ultimately lead to a more sustainable heat supply for domestic hot water and space heating in the European Union.

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Keywords: Solar district heating; large-sclae solar thermal system; season pit storage; absorption heat pumps;

1. Introduction

Graz is the second largest city in Austria and capital of the federal state Styria. It is located in the southeast and has an estimated population of 273.744 [1]. District heating (DH) is well established and plays an essential role in deploying heat and hot water for residential and service buildings in Graz. It started in 1963 by the inauguration of a DH power station. A steam generator with connected turbines was used for producing electricity and its excess heat was used to provide heat and hot water to the surrounding buildings [2]. Over the years the share of heat supply by DH increased by a steady extension of the grid utility and became a central part of heat provision in Graz.

2. District heating in Graz

Current energy used for heating and hot water in residential and service buildings in Graz is estimated at 2,400 gigawatt hours per year (GWh/a). In total, 1,100 GWh/a (2013) are provided by DH. While Graz receives 935 GWh per year, corresponding to 39% of the cities heat demand, the remaining 165 GWh/a are distributed beneath the southern communities around Graz, which are obtaining heat from DH mainly in winter [3].

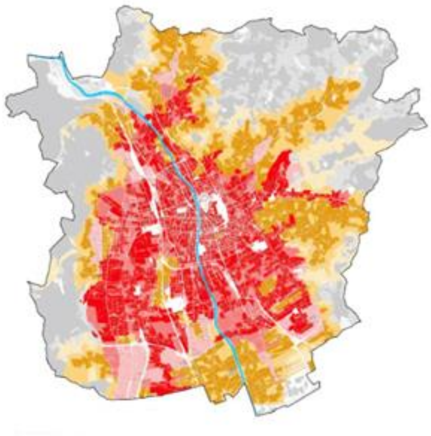

Fig. 1. Overview of current and planned district heating areas in Graz (red).

It is planned to further increase the share of DH up to 56% until 2030. Figure 1 illustrates the current DH net of Graz, including planned extensions of the grid. While dark red areas mark the current DH net, slightly red areas depict planned extensions until 2020. Orange areas indicate the gas supply network of Graz. The DH system is a pressurized water system. Operating temperatures vary seasonally. The system is operated with flow temperatures up to 120°C in winter and up to 75°C in summer. The return flow temperature is on average 60°C [2]. The DH grid is operating all seasons throughout the year in Graz, whereas the southern communities are not supplied in summer. DH pipes in Graz exhibit a diameter between 25 and 600 mm. Within these diameters, different types of pipes (main transport, side and house service) are installed [2].

Table 1 illustrates data of the current DH net of Graz and its southern communities referred as *GU Süd*.

Table 1. Data of current district heating in Graz including the southern communities of Graz.

	City Graz	Southern communities around Graz (GU Süd)
Total heat amount per year (incl. distribution losses)	~ 1050 GWh [2013]	165 GWh [2013]
Share winter term	~ 84%	~ 90%
Peak load (February 2012, outside air temperature -13.4°C)	425 MW	70 MW
Flow temperature raised up to max.:	120°C	110°C (Subnets 90°C)
Route length	~ 370 km	~ 201 km
Transmission stations	~ 5,700	~ 3,000

The DH grid in Graz is operated by the local energy provider Energie Graz GmbH, whereas the regional energy provider Energie Steiermark Wärme GmbH (Energie Steiermark) is responsible for the provision and the feed-in of the thermal energy. Energie Steiermark feeds in heat from their DH central station in Puchstrasse and via an additional pump station located in the southwest of Graz.

Heat for DH is emerging from various power plants, but primarily from combined heat and power (CHP) plants [8]. The most important ones are the CHPs in Mellach and Werndorf-Neudorf, two power plant parks located 15 to 20 km south of Graz. These CHP plants are operated by the Austrian energy provider Verbund Thermal Power GmbH & Co KG (VTP). With an overall share above 75% these CHPs are the most important heating source for DH in Graz [4]. Each park consists of two CHPs. Mellach I+II with an old coal-fired CHP with a maximum thermal output of 230 MW and a high-efficient gas-fired CHP plant with a maximum thermal output of 400 MW established in 2012. Established in 1975, both plants in Werndorf, in the meanwhile, are put out of operation. The Werndorf II plant was in operation until 2014. It is mainly fired with heavy oil and has a maximum thermal output of 200 MW [8]. Energie Steiermark has a heating supply contract with VTP in order to meet the heat demand for DH in Graz. Other heat sources for DH are the old CHP plant at Puchstrasse industrial waste heat from a gas turbine plant (CMST Magna Steyr) and a steel factory, and three solar thermal plants [4]. However, the plant at Puchstrasse which is operated by Energie Steiermark is only running as DH plant for peak loads in winter.

Table 2 illustrates the DH generation for Graz and its southern communities by plant. Moreover, it shows the used fuel and detailed numbers for thermal capacity, the yearly heat provided and share of each plant. It has to be noted that the illustrated yearly heat supply is an average between 2006 and 2011. Data of the modern CHP Mellach II are not available since it just operated during a test phase.

Table 2. DH generation for Graz and the southern communities around Graz listed by power plant
[[1]theoretical maximum output; [2]average between 2006 – 2011; [3]CHP Mellach II only operated during a test phase;
[4]solar output 2012. [5]not in operation anymore].

DH generation	Used fuel	Thermal output [MW]	Heat supply [MWh/a]	Share [%]
CHP Mellach I	Coal	230	696,196[2]	66.25
CHP Mellach II	Natural gas	400	0[3]	0
CHP Werndorf I+II[5]	Oil, Natural gas	200	114,956	10.94
DH power plant Puchstrasse	Natural gas	280	98,832[2]	9.40
CMST Magna Steyr (Thondorf)	Industrial waste heat	35	95,051[2]	9.04
Steel factory Marienhuette	Industrial waste heat	15	42,050[2]	4.00
Solar thermal plants (Liebenau, Andritz, AEVG)	Solar power	7.2[1]	3,799[4]	0.36

Overall	**1,167.2**	**1,050,881**	**100**

Due to recent events on the European electricity market and consequential low electricity prices the modern gas-fired CHP plant Mellach II was put out of operation in 2014. The massive drop of electricity prices caused VTP to shut down their power plants in Mellach and Werndorf-Neudorf [7]. The shutdown of these plants highly affected the availability of heat for DH in Graz, since more than 75% covered by CHP park Mellach. However, due to a court's interim conjunction VTP was not allowed to fully shut down Mellach II, since it has to serve as a standby unit for the old coal-fired DH plant at Puchstrasse [3]. Since there is still the binding heating supply contract between VTP and Energie Steiermark until 2020 with an agreed thermal output of 230 MW the coal-fired CHP Mellach I is still in operation, but due to its construction in 1986 already in the end phase of its operating lifetime [5].

The trend on the European electricity market in the last years with rapidly sinking electricity prices leads to significant changes in operating modern high efficient CHP plants. Electricity provider, such as VTP, are being put under pressure since cost-intensive modern CHP plants, such as the one in Mellach, are not that economically sound anymore. This ultimately leads to a dilemma for cities which are highly dependent on waste heat of these CHPs. Though the closure of the CHP plants in Mellach and Werndorf-Neudorf no cheap waste heat from electricity generation is available anymore and has subsequently a substantial impact on the future heat supply for DH in Graz.

DH in Graz is definitely playing a key role in future which can be seen in the planned extension in Figure 1 (slight red colored areas) and therefore is indicating a continuous growing demand for thermal energy in 2020 and 2030. Where in 2013 632 MW were provided by DH, an increase up to 730 MW and 830 MW respectively until 2020 and 2030 are being expected. Additionally, Graz is based in a unique basin, where especially in winter the necessary air exchange is hampered and therefore has a high rate of pollution and respirable dust namely PM10 and NO2 (Nagl et al. 2015). This means that, due to the missing waste heat from the CHPs by the ending heating supply contract in 2020, the growth in heat demand by grid extension and consumption behavior and the associated problems with high concentrations of PM_{10} and NO_2, Graz is facing a quite complex challenge in providing heat in future [8].

Therefore, the city senate of Graz constituted a project team in order to find and analyze various options for the future heat provision by DH in Graz for 2020 [5]. Main objectives were enacted, that have to be considered within the analysis. The main objectives were namely, (1) no deterioration of the primary energy factor of DH-generation, (2) no deterioration of specific greenhouse gas emissions (g/kWh), (3) consideration of current emissions in Graz, (4) no increase of costs compared to other types of heating and (5) security of supply and quality [6]. Several working groups were established and different experts and stakeholders were involved in an open discussion process to find possible solutions for the future heat supply for DH of Graz. In total, 9 workshops were held with more than 200 experts participating in order to find both short-term and long-term solutions for the future heat provision [5]. Short-term actions are the construction of a 195 MW gas-fired boiler site and a 5 MW biomass heating plant, a further increase in decoupling waste heat from industry processes and several minor enhancements in the actual infrastructure [6]. The gas-fired boiler plant is currently under construction next to the old DH plant at Puchstrasse and will start operating in winter 2016/17. It is constructed as a safety precaution and serves as a back-up for possible drop outs of the older sites such as the old DH plant at Puchstrasse [8]. Long-term actions are building refurbishments for increasing energy efficiency and the development of a clear concept for future large-scale low-carbon power plants in geothermal, biomass and solar thermal heating.

One promising concept, which has been initiated by one of the workshops, could be the integration of a large-scale solar thermal plant in combination with seasonal heat storages and absorption heat pumps (AHPs). This concept exceeds the size of current constructed large-scale solar thermal plants with seasonal heat storages in Denmark by far. Especially, the approach of including AHPs to the concept is total new and offers great potential on the one hand for the complex preconditions of DH in central Europe and on the other hand for utilizing solar heat efficiently for the whole year. Furthermore, for the unique situation in Graz the concept offers a substantial potential in terms of provision and security of supply of heat and hot water for future DH in Graz. Therefore, Energie Steiermark agreed to carry out a feasibility study of the concept in order to analyze its potential in detail.

3. BIG Solar Graz: Techno-economic feasibility study

3.1. Overview of the feasibility study

In 2015 *Energie Steiermark* assigned the company *Gesellschaft für Solarinstallation und Design mbH* (S.O.L.I.D.) to investigate the potential of solar district heating (SDH) in Graz. The focus of the study is to analyse the technical and economic potential of integrating a centralized large-scale solar thermal system including seasonal pit storage and absorption heat pumps for DH in Graz. In order to get a full and detailed analysis the scope of the study was chosen deliberately broad. Several collaborative partners were involved. The Danish company *PlanEnergi* with profound knowledge and great experience in system modelling and dynamic simulation of large solar thermal systems with seasonal storages and the urban energy agency *Grazer Energieagentur* were involved. Moreover, the study was partly funded by the Austrian Research Promotion Agency, the Climate and Energy Fund, the Province of Styria and the City of Graz.

Since a broad variety of topics had to be investigated the study has been divided in specific work packages (WPs) for getting a full and detailed analysis of the potential of such a concept for Graz.

The work packages are the following:

WP 1: Collection of basic data & analyzation of boundary conditions
WP 2: Dynamic simulation of energy balance
WP 3: Economic analysis
WP 4: Financing and Business Case
WP 5: Assessment of available land
WP 6: Legal framework
WP 7: Storage

3.2. Technical concept

The concept BIG Solar aimed to investigate a maximum solar fraction applicable limited to the basic condition of having a competitive heat price compared to other sources of heat generation such as from gas boilers for DH in Graz. Therefore, the size and capacities of the key components namely the collector field, pit storage and the absorption heat pumps (AHPs) were simulated between a certain range in order to find a system optimum for dimensioning each component and ultimately for the whole system. Especially, the use of AHPs is a key element in the system. AHPs are used on the one hand for raising the temperature coming from the seasonal storage, when the storage is already partly emptied and temperature is lower than the minimum necessary 80 to 90°C for DH. On the other hand, AHPs accelerate the cooling down process of the seasonal pit storage, which means higher collector-efficiency at lower temperatures and therefore leading to an essential yield improvement of the specific net solar heat production.

Figure 2 shows the concept of BIG Solar Graz with its key components. Moreover, the concept foresees an auxiliary heating component, which on the one hand serves to power the generator of the AHPs and on the other hand for raising the temperature from the BIG Solar system up to the required 120°C for DH in winter.

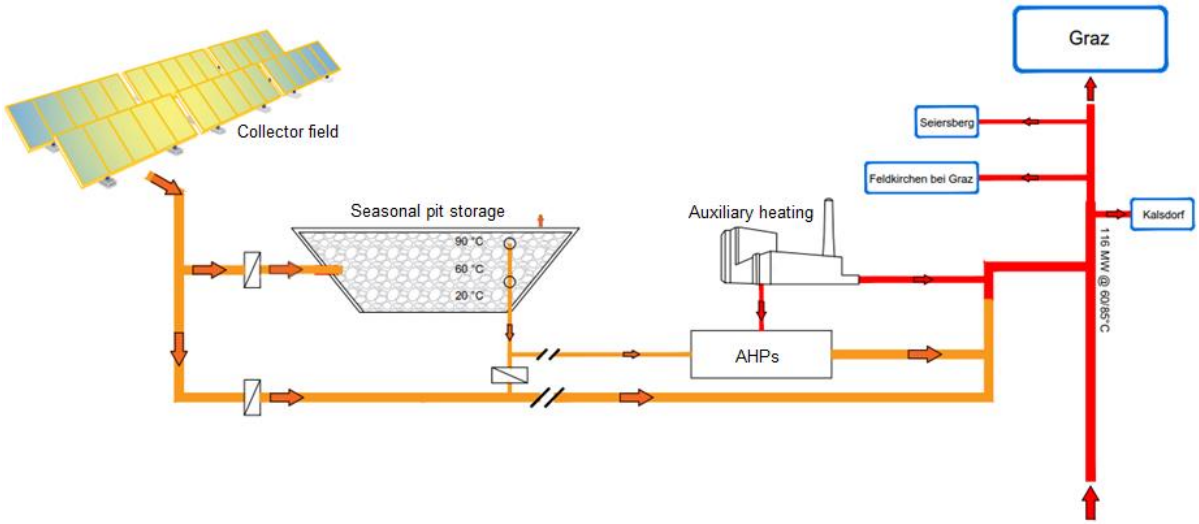

Fig. 2. BIG Solar Graz concept.

First, for estimating the overall potential of the concept the heat load profile of DH in Graz was divided into two shares. A low temperature share for the basic heat load, provided either from solar and the storage directly and from the storage via the AHPs indirectly and a high temperature share, which is mainly for peak load especially in winter, provided by high temperature sources such as gas or biomass boilers. These two temperatures shares are illustrated in Figure 3, where orange is the low temperature share which theoretically could be covered by the BIG Solar concept and blue the share for the high temperature sources. According to this calculation the BIG solar share may be roughly at 55% of DH in Graz with the current boundary conditions. Moreover, by taking into account that only one part of the energy is supplied by solar and the other part is supplied by the driving energy for the thermal AHPs from a auxiliary heating source the pure solar output would be 33%. Therefore, detailed investigations of the concept were performed up to a solar fraction of 30%.

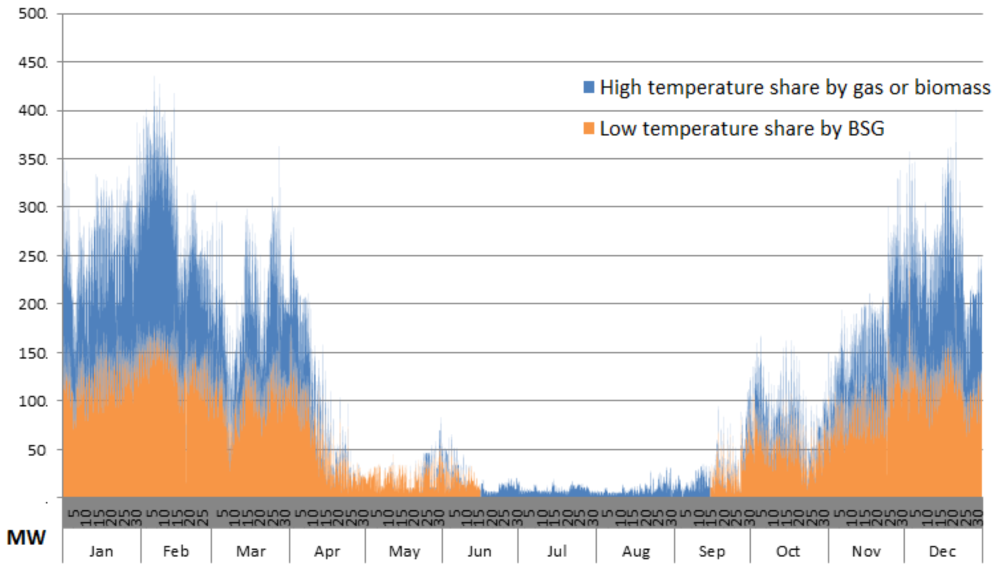

Fig. 3. Yearly heat load profile of DH in Graz divided in temperature needs.

Simulating the feed-in of possible BIG Solar scenarios into DH net of Graz was a major part of the feasibility study. For having detailed data synchronization, a representative heat load profile of DH in Graz was taken into account. Data of 2014 were used as a basis. By using TRNSYS, a transient system simulation software tool, multiple simulations were being performed up to a maximum solar fraction of 30% in order to evaluate the optimum in both, its technical and economic practicability. Therefore, a series of simulations for collector field sizes between 20,000 m² up to 1 Million m², pit storage sizes between 100,000 m³ up to 2 Million m³ and 3 different sizes of AHPs (0, 50 and 100 MW heat output) were performed and evaluated.

4. Results of the techno-economic feasibility study

The multiple TRNSYS simulations with the different parameter variations resulted in a techno-economic optimum of 450,000 m² collector field area, a seasonal heat storage capacity of 1,800,000 m³ and AHPs with a total heat capacity of 100 MW. Within the analysis technical limitations such as the maximum capacity of the DH transport line, current heat and temperature loads, but also future heat loads by the consideration of future waste heat potentials from industries, were taken into account. Furthermore, a comprehensive cost evaluation was performed by using capital budgeting. The most important economic key performance indicators (KPIs) such as net present value (NPV), internal rate of return (IRR), discounted payback period (DPB) and levelized cost of energy (LCOE) were calculated and evaluated for different financing scenarios. However, specific data of cost estimations are not being published due to confidentiality.

Figure 4 illustrates the simulated heat production for the DH net in Graz with the techno-economic optimum BIG Solar Graz concept. Heat production is divided by months and shows the different sources which are used to meet the overall heating demand. Over the year the energy supplied from solar amounts to roughly 200 GWh. Over two thirds of the total solar provided energy is heated up by the AHPs.

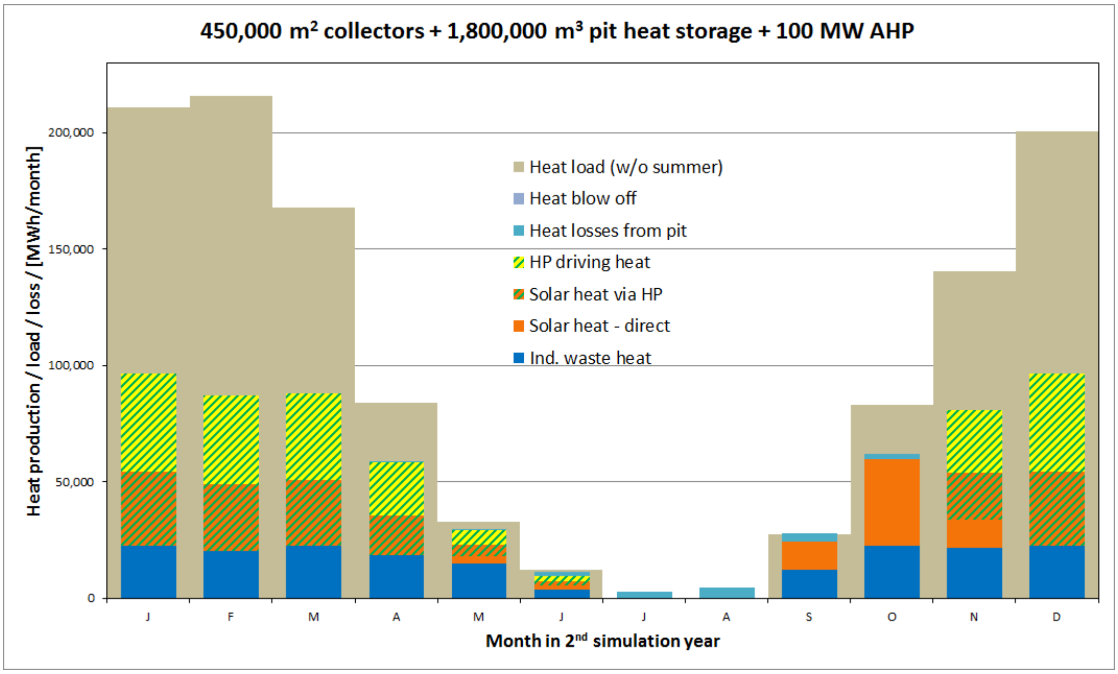

Fig. 3. Monthly heat production for DH in Graz by the techno-economic optimum scenario of the BIG Solar concept.

Simulations show that the BIG Solar concept is technical and economic feasible. The economic analysis shows that a heat price is comparable to other heating sources for DH in Graz. Although such a system has high upfront investment costs the payback-time is moderate and economically reasonable, even with neglecting the additional environmental benefit. Moreover, it has to be said that on both, a technical and an economic point of view, the project is quiet flexible. This means that giving the boundary conditions in Graz including land availability, the size of the solar system can vary between 150,000 and 650,000 m² respecting the adaptation of sizes of the pit storage and the AHPs by feasible and economic sound price ranges. However, some issues have to be still investigated in more detail, which were not addressed in this feasibility study and are part of a later planning phase.

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