BILLY SOLAR: SCALABLE AND COST-EFFECTIVE SOLAR HEATING UNITS FOR INDUSTRY

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Abstract

Here we present preliminary results of the Billy Solar project, which pursues the goal of developing a fully configured and modular scalable solar heating system for industrial use at different production sites and for different processes. For this purpose, a "one size fits all" concept will be developed based on simulation together with collector manufacturers, software developers, application partners from industry and research institutes. The system consists primarily of solar thermal collectors and a heat storage. As an alternative to solar thermal, photovoltaics combined with heat pumps or possibly a combination of both approaches are investigated. Based on this, financing models are derived.

Keywords:solar process heat, modular, load profiles

1. Introduction

An increasing number of industrial companies are reducing their CO_2 footprint by using heat from solar energy. Although the number of solar thermal systems for generating solar process heat more than quadrupled from 120 to 500 between 2012 and 2016 worldwide [1] the potential for solar process heat is still almost untapped. Most of these solar heating systems are the result of tailor-made individual planning, which makes them less attractive for industrial companies. The objective of the Billy Solar project is to boost the deployment of solar heat in industry and give an alternative approach to the traditional planning, where solar thermal installations in industry require literally months of project planning and energy calculations and a lot of experience with such systems. Often, the cost of planning and the complex integration scheme challenges the project. Until now solar process heat systems have been designed for specific requirements for each type of costumer making it expensive and thus limiting its desirable extensive deployment. Thus in Billy Solar we investigate a more standardised approach by the development of an adaptable modular system and the analysis of the energy demand of various industries.

For this purpose a "one size fits all" concept will be developed based on system simulations. This concept will be applied to different sites with various process heat demands. Because the heating system is not tailor-made, there will be deviations from the ideal configuration at a single integration site. The big advantage, however, is that the high planning effort for each individual integration is eliminated and a system can be put together in which all components fit together ideally and which is composed of modular units. A unit consists primarily of a solar thermal system with storage. As an alternative to solar thermal energy, photovoltaics combined with heat pumps or a combination of both approaches will be investigated as well. Based on this, financing models will be derived.

2. Method

For the development of the modular heat units, typical industrial load profiles are first identified by:

1. classification according to energy consumption per process, process requirements (temperature, load profile, storage possibilities), specification of the energy supply network, connection to district heating, options for waste heat utilization

2. data extraction from existing data from energy flow and pinch analyses.

Based on this typical load profiles and their specifications (temperature, pressure, medium, load profile, etc.), modular units (solar thermal, photovoltaic and heat pump) for the provision of a certain amount of heat are developed simulation-based with the software Polysun. These units consist of a basic unit and allow easy

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upscaling. For this purpose, the Polysun tool will be extended to map complex industrial boundary conditions.

Finally, the costs of the overall system will be examined and worked out on the basis of various scenarios and business models in cooperation with the various interest groups (collector manufacturers, industrial partners, energy suppliers, etc.).

3. Preliminary Results

By examining energy consumption data, temperature levels and other data from pinch analyses collected for various companies and sites by the project partner HSLU, several recurring heat sink profiles could be identified, e.g. from galvanizing and painting basins.
In addition, questionnaires were prepared which allow for a rough energetic analysis and give relevant information on process level, which is important for the development of the heat units and for possible energetic efficiency measures. The questionnaire is based on the freely-available Solind Tool [2]. These questionnaires were completed for seven different production sites of Emmi, the biggest dairy in Switzerland.

Various recurring processes were identified as suitable heat sinks for a standardized solar thermal integration (e.g. cleaning, pasteurization). Furthermore, the Polysun software has been extended in such way that complex industrial profiles and their heat consumption can be integrated relatively easily. By means of simulations the parameters of the systems (type of collector technology, collector field area, volume of the heat storage tank, irradiation and process heat consumption) were varied and the system was optimized according to energetic and economic aspects (system, integration and installation costs). The simulations carried out in the examined industrial plants and processes result in different solar fractions depending on the varied parameters. For the design of the optimal solar thermal system, the system costs play a decisive role in addition to the solar heat yield. Here the term "optimal" solar thermal system describes the most economical combination of collector field size and storage volume with the lowest system costs per energy unit produced. The system costs refer to solar collectors including all components in the collector circuit (collector, elevation, pipes, pumps, heat exchanger, accessories, etc.) up to the heat exchanger for the heat transfer from the solar circuit to the heat supply circuit of the company as well as the installation. Different cost functions were used to define the system costs depending on collector technology and storage volume and are based on offers for large-scale systems from various research projects and for the heat storage tanks on price lists from manufacturers [3] [4].

With the help of these cost functions, the simulated solar heat yield from the simulation study can be assigned and the levelized cost of heat (LCoH) can be determined for the simulated version. To calculate the LCoH, the definition of the heat price according to IEA SHC Task 54 in Formula 1 was used.

Formula 1: Calculation of the Levelized Cost of Heat (LCoH) in CHF/MWh

$$LCoH = \frac{I_{Sol} + \sum_{t=1}^{T} \frac{C_{t,Sol}}{(1+r)^t} - S_{Sol}}{\sum_{t=1}^{T} \frac{E_{t,Sol}}{(1+r)^t}}$$

$I_{sol} = Total\ investment\ cost$ $r = Tax\ rate\ in\ \%$

$C_t = annual\ operation\ cost$ $T = amortisation\ time\ in\ year$

$E_t = annual\ solar\ yield\ in\ MWh$ $S_{sol} = Subsidy$

By means of linear interpolation between the simulated collector field sizes and heat storage volumes from the simulation study, profitability matrices can be presented for the operations and processes (Figure 1). The solar heat production costs have been calculated over a period of 25 years at an interest rate of 3% and without ongoing operating costs. The representation with color coding of the lowest solar heat prices of an enterprise makes it possible to identify the suitable combination sizes from collector field size and storage volume. As an example, Figure 1 shows the profitability matrix for the LCoH for a company in Switzerland using flat plate collectors to provide process heat up to 80°C.

LCoH CHF/ MWh

Storage size [m3]

Collector field [m2]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250
100	185.2	119.9	127.9	135.7	143.3	150.9	149.6	148.5	147.6	146.7	145.9															
200	170.5	115.1	116.2	117.3	118.3	119.3	120.1	120.8	121.5	122.2	122.8															
300	160.6	110.1	108.9	107.7	106.6	105.7	106.7	107.7	108.7	109.7	110.6															
400	153.5	106.1	103.6	101.4	99.4	97.6	98.7	99.7	100.8	101.8	102.8															
500	148.0	102.7	99.6	96.9	94.3	92.0	93.1	94.1	95.1	96.2	97.1															
600	146.1	104.3	100.8	97.6	94.7	92.1	92.6	93.1	93.6	94.0	94.5															
700	144.3	105.1	101.3	97.8	94.7	91.9	91.9	92.0	92.1	92.1	92.2															
800	142.4	105.5	101.4	97.8	94.4	91.4	91.2	90.9	90.6	90.4	90.2															
900	140.6	105.6	101.4	97.5	94.0	90.9	90.4	89.8	89.3	88.8	88.4															
1000	139.0	105.5	101.1	97.1	93.6	90.3	89.5	88.8	88.1	87.4	86.8	88.3	89.8	91.3	92.9	94.5	95.2	95.9	96.6	97.3	98.0	98.9	99.8	100.8	101.7	102.6
1100	141.5	110.0	105.1	100.8	96.8	93.2	92.3	91.5	90.7	89.9	89.1	90.4	91.8	93.1	94.5	95.8	96.5	97.1	97.7	98.3	98.9	99.7	100.5	101.3	102.1	102.8
1200	143.5	114.1	108.8	104.0	99.7	95.9	94.8	93.9	92.9	92.0	91.1	92.3	93.5	94.6	95.8	97.0	97.5	98.1	98.6	99.1	99.6	100.3	101.0	101.6	102.3	103.0
1300	145.2	117.8	112.0	106.9	102.3	98.2	97.1	96.0	94.9	93.9	92.9	93.9	94.9	95.9	96.9	98.0	98.4	98.9	99.3	99.7	100.2	100.8	101.3	101.9	102.5	103.0
1400	146.6	121.2	115.0	109.5	104.7	100.3	99.0	97.8	96.7	95.6	94.5	95.4	96.2	97.1	97.9	98.8	99.1	99.5	99.9	100.3	100.6	101.1	101.6	102.1	102.5	103.0
1500	147.8	124.2	117.7	111.9	106.8	102.1	100.8	99.5	98.3	97.1	95.9	96.6	97.3	98.0	98.7	99.4	99.8	100.1	100.4	100.7	101.0	101.4	101.8	102.2	102.5	102.9
1600	148.7	127.1	120.2	114.1	108.7	103.8	102.4	101.0	99.7	98.4	97.2	97.8	98.3	98.9	99.5	100.0	100.3	100.5	100.8	101.0	101.2	101.6	101.9	102.2	102.5	102.8
1700	149.5	129.6	122.4	116.0	110.4	105.3	103.8	102.4	101.0	99.6	98.3	98.8	99.2	99.6	100.1	100.5	100.7	100.9	101.1	101.2	101.4	101.7	101.9	102.2	102.4	102.6
1800	150.2	132.0	124.5	117.8	112.0	106.7	105.1	103.6	102.1	100.7	99.3	99.6	100.0	100.3	100.6	100.9	101.0	101.2	101.3	101.4	101.6	101.7	101.9	102.1	102.3	102.4
1900	150.7	134.2	126.4	119.5	113.4	108.0	106.3	104.7	103.1	101.6	100.2	100.4	100.6	100.8	101.0	101.2	101.3	101.4	101.5	101.6	101.6	101.8	101.9	102.0	102.1	102.2
2000	151.2	136.2	128.1	121.0	114.7	109.1	107.3	105.6	104.0	102.5	101.0	101.1	101.2	101.3	101.4	101.5	101.5	101.6	101.6	101.6	101.7	101.7	101.8	101.9	101.9	102.0
2100	151.5	138.1	129.7	122.3	115.9	110.1	108.3	106.5	104.9	103.3	101.8	101.8	101.7	101.7	101.7	101.7	101.7	101.7	101.7	101.7	101.7	101.7	101.7	101.7	101.7	101.7
2200	151.8	139.8	131.2	123.6	116.9	111.0	109.2	107.4	105.6	104.0	102.4	102.3	102.2	102.1	102.0	101.8	101.8	101.8	101.7	101.7	101.7	101.6	101.6	101.5	101.5	101.5
2300	152.0	141.4	132.5	124.8	117.9	111.9	109.9	108.1	106.3	104.6	103.0	102.8	102.6	102.4	102.2	102.0	101.9	101.8	101.8	101.7	101.6	101.5	101.5	101.4	101.3	101.2
2400	152.2	142.9	133.8	125.8	118.8	112.7	110.7	108.8	106.9	105.2	103.6	103.2	102.9	102.7	102.4	102.1	102.0	101.9	101.8	101.7	101.6	101.4	101.3	101.2	101.0	100.9
2500	152.3	144.3	134.9	126.8	119.7	113.4	111.3	109.4	107.5	105.7	104.0	103.6	103.3	102.9	102.5	102.1	102.0	101.9	101.7	101.6	101.5	101.3	101.1	101.0	100.8	100.6
2600	155.9	147.4	137.7	129.3	122.0	115.5	113.3	111.3	109.4	107.5	105.7	105.3	105.0	104.6	104.2	103.8	103.7	103.5	103.4	103.2	103.1	102.9	102.7	102.5	102.4	102.2
2700	159.5	150.4	140.4	131.8	124.2	117.5	115.3	113.2	111.1	109.2	107.3	107.0	106.6	106.2	105.8	105.5	105.3	105.1	105.0	104.8	104.6	104.4	104.2	104.0	103.9	103.7
2800	163.0	153.3	143.0	134.1	126.3	119.5	117.2	114.9	112.8	110.8	108.9	108.5	108.2	107.8	107.4	107.1	106.9	106.7	106.5	106.3	106.1	105.9	105.7	105.5	105.3	105.1
2900	166.3	156.1	145.6	136.4	128.4	121.4	119.0	116.7	114.5	112.4	110.4	110.0	109.7	109.3	108.9	108.6	108.4	108.2	108.0	107.7	107.5	107.3	107.1	106.9	106.7	106.5
3000	169.6	158.9	148.0	138.6	130.4	123.2	120.7	118.3	116.1	113.9	111.8	111.5	111.1	110.8	110.4	110.1	109.8	109.6	109.4	109.1	108.9	108.7	108.5	108.2	108.0	107.8
3100	172.9	161.5	150.4	140.8	132.4	125.0	122.4	119.9	117.6	115.4	113.2	112.9	112.5	112.2	111.8	111.5	111.2	111.0	110.7	110.5	110.3	110.0	109.8	109.5	109.3	109.1
3200	176.0	164.1	152.7	142.8	134.2	126.7	124.0	121.5	119.1	116.8	114.6	114.2	113.9	113.5	113.2	112.8	112.6	112.3	112.0	111.8	111.5	111.3	111.0	110.8	110.6	110.3
3300	179.1	166.6	154.9	144.8	136.1	128.4	125.6	123.0	120.5	118.1	115.9	115.5	115.2	114.8	114.5	114.2	113.9	113.6	113.3	113.0	112.8	112.5	112.3	112.0	111.8	111.5
3400	182.1	169.0	157.1	146.8	137.8	130.0	127.1	124.4	121.8	119.4	117.1	116.7	116.4	116.1	115.8	115.4	115.1	114.8	114.5	114.3	114.0	113.7	113.4	113.2	112.9	112.7
3500	185.0	171.4	159.2	148.7	139.5	131.5	128.6	125.8	123.2	120.7	118.3	117.9	117.6	117.3	117.0	116.7	116.4	116.0	115.7	115.4	115.1	114.9	114.6	114.3	114.1	113.8
3600	187.9	173.7	161.2	150.5	141.2	133.0	130.0	127.1	124.4	121.9	119.4	119.1	118.8	118.5	118.2	117.9	117.5	117.2	116.9	116.6	116.2	116.0	115.7	115.4	115.1	114.9
3700	190.7	175.9	163.2	152.2	142.8	134.5	131.4	128.4	125.7	123.0	120.5	120.2	119.9	119.6	119.3	119.0	118.7	118.3	118.0	117.7	117.3	117.0	116.8	116.5	116.2	115.9
3800	193.4	178.1	165.1	154.0	144.3	135.9	132.7	129.7	126.9	124.2	121.6	121.3	121.0	120.7	120.4	120.1	119.8	119.4	119.1	118.7	118.4	118.1	117.8	117.5	117.2	116.9
3900	196.1	180.2	167.0	155.6	145.8	137.2	134.0	130.9	128.0	125.3	122.6	122.3	122.1	121.8	121.5	121.2	120.8	120.5	120.1	119.7	119.4	119.1	118.8	118.5	118.2	117.9
4000	198.7	182.3	168.8	157.3	147.3	138.5	135.2	132.1	129.1	126.3	123.6	123.3	123.1	122.8	122.5	122.2	121.9	121.5	121.1	120.7	120.4	120.0	119.7	119.4	119.2	118.9

Figure 1: Example for a LCoH matrix for a solar process heat field with flat plate collectors. Here the solar process heat system is simulated with different collector field sizes and storage volumes with color coding from the highest heat prices in red to the lowest in green

Figure 1 shows that the economically most promising range for this exemplary case study begins with a collector field size of 2500 m^2 and a storage volume of 80-90 m^3 upwards. The lowest solar heat price of 83.7 CHF/MWh is achieved for this example a large collector field size of 5'000 m^2 and a heat storage tank volume of 250m^3. This results indicates, that bigger systems lead to lower prices, however this limit was set in this project due to the space restrictions in the company.

The LCoH matrix was calculated for all investigated companies and production sites. This resulted in a first estimation for the dimensioning of a smallest standard module for industrial solar thermal systems, which has a collector field area of 100 m^2 and a hot water storage tank with 10 m^3. These interim results have to be confirmed and refined in the course of the project. Figure 2 shows the investigated industrial sites, their heat consumption and average required process temperature. The color-coded area indicates a range for the heat production costs for the optimal size of the solar unit (collector area and storage tank). In the BillySolar project different economic scenarios were calculated, here in Fig. 2 the heat price is shown without and including operating costs. On the one hand, it can be seen that the heat price is inversely related to the total energy consumption of the company. Furthermore, a tendency to increased solar heat prices for higher process temperatures can be identified. This is caused by a decreasing solar yield for higher operation temperatures of the solar collectors.

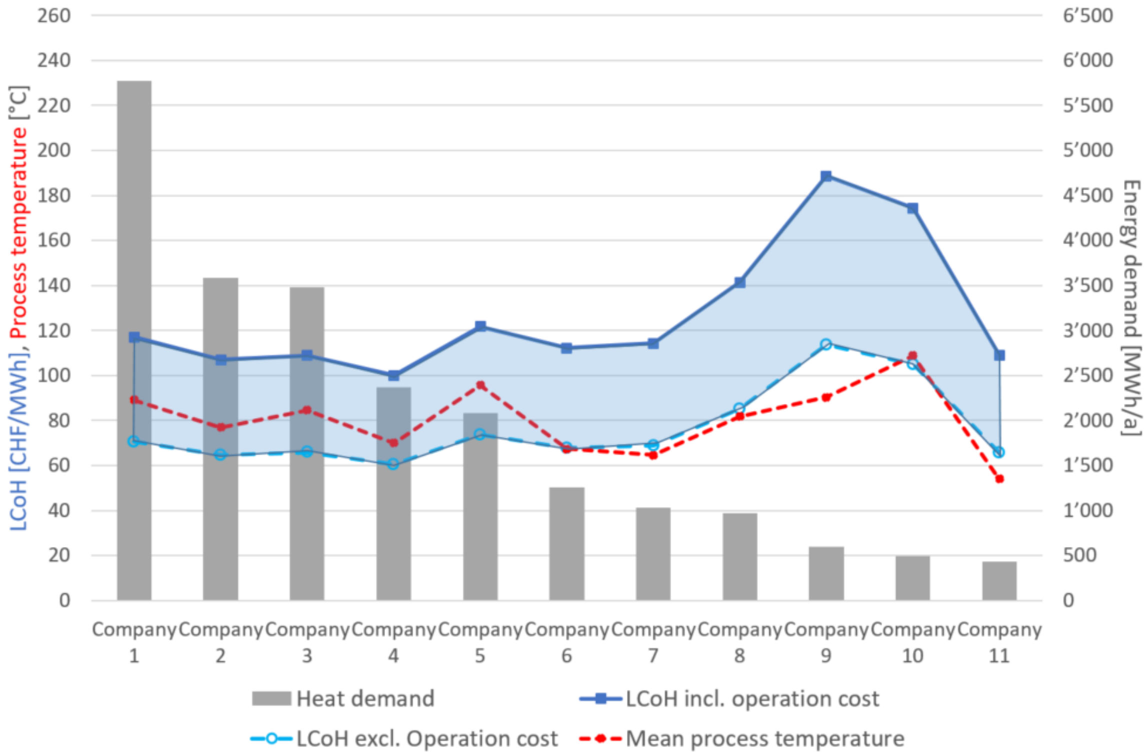

Figure 2 Heat price for vacuum tube collector unit (blue area between solid and dashed line, left axis) according to energy demand (grey bars, right axis) and process temperature (red dashed line, left axis)

4. Outlook

The next step is to investigate a photovoltaic heat pump (PV-HP) unit with different heat sources (outside air, waste heat) for the previously investigated industrial sites and compare it with the solar thermal (ST) units. A system based on PV-HP will in most cases not be operated independently from the power grid. Therefore, a system design can only be made in connection with economic parameters (especially the feed-in and purchase tariffs for electricity at the respective site). From comparison studies between the technologies, scenarios and optimal conditions it will be determined in which case either the use of solar thermal energy, a PV-HP system or a combination of these technologies is more advantageous for the industrial end user.

Furthermore, the interaction of several units during upscaling and their combination (ST supplemented with PV-HP, possibly also integration of waste heat into the smallest unit), based on concrete process data, will be investigated by means of simulations. In this process, the combination and dimensioning of components (ST and PV-WP, if necessary, additional waste heat, district heating) will be coordinated and optimized.

Finally, possible financing options will be considered. Currently, the financing of solar process heat plants in Switzerland is done through general construction financing, there are no special programs or project financing. Since solar plants are planned individually for the use at the respective location, the financing of existing plants is also individually tailored to the respective owner. The conditions are to be improved by standardizing the units, easy dismantling and a broad customer structure connected to heating networks. Against this background, models involving industry as prosumer as well as contracting and leasing models are to be investigated.

References

[1] "Solarwirtschaft," [Online]. Available: https://www.solarwirtschaft.de/presse/pressemeldungen/pressemeldungen-im-detail/news/neue-internetseite-zeigt-vorteile-von-industrieller-prozesswaerme-in-drei-sprachen.html..

[2] S. I. f. Solartechnik, “SPF Solind Tool,” 2019. [Online]. Available: https://www.spf.ch/index.php?id=19086.

[3] B. M. e. al, “Deliverable B2: Integration Guideline,” IEA SHC Task 49 SolarPaces Annex IV, 2015, 2015.

[4] I. M. u. F. Ruesch, “Machbarkeit solarunterstützter Wärmenetze im Kanton St.Gallen,” Bundesamt für Energie BFE, 2017.