Sensitivity Analysis of Solar District Heating Systems

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Abstract

The economic consideration of large-scale solar thermal systems to support district heating is often a challenge. Due to the necessary planning efforts and high investment costs of the solar thermal components, the solar-supported scenario is often ruled out. Therefore, the present work deals with a tool where an approximate economic sensitivity analysis can be carried out at the beginning stage of the planning process. This includes the calculation of the levelized cost of heat (LCoH) and the comparison with conventionally operated district heating systems. Further, by using cost functions of solar thermal systems and thermal energy storages, a preliminary calculation of the investment costs of solar supported district heating in different variations is made possible. The calculation of the LCoH considers the energy prices, lifetime of the components, costs for CO_2-emissions, increase of energy prizes, etc. By varying the mentioned parameters, a sensitivity analysis of the LCoH is performed and analyzed over the lifespan of the system. To validate the tool, results from completed projects were recalculated and interpreted. To do this, different scenarios are defined, LCoHs are calculated and a sensitivity analysis for each scenario is carried out. The results show a consistent correlation between the individual project results and the calculation methods.

Keywords: solar district heating, levelized cost of heat, sensitivity analysis

1. Introduction

Climate change presents new global challenges for our society. Both political and technical solutions are therefore being sought on a global scale. The European Union (EU) has established new benchmarks in climate policy with the introduction of the “Green Deal”. A central objective of the Green Deal is the reduction of greenhouse gas emissions by 55% by 2030. Additionally, the goal is to achieve complete climate neutrality by 2050 (European Commission, 2021). In order to achieve this goal, the energy sector in particular is facing major challenges, as it is responsible for 75% of the greenhouse gas emissions in the EU (European Commission, 2023a). It is evident that within the energy sector, heating and cooling (H&C) has the potential to play a pivotal role in decarbonizing the energy system. Given that H&C accounts for about 50% (European Commission, 2023b) of the final energy demand in the EU, it is clear that this must be a key focus for decarbonization efforts. Presently, the share of renewable energy sources utilized in the H&C sector in only marginally above 23%, and the majority of energy consumption is still reliant on fossil fuels (European Commission, 2023b).

The European Commission identifies district heating, including the integration of renewable energy sources, as a key technology for the decarbonization of the H&C sector (European Commission, 2022). For instance, the use of solar thermal district heating offers an obvious solution for integrating renewable energy sources into district heating systems. It is indisputable that the integration of solar systems in district heating networks can be technically and successfully implemented. A significant number of solar district heating systems are in operation, particularly in Denmark (Tian et al., 2019). Nevertheless, the share of solar thermal energy supplied to district heating systems in the EU is currently only 0.1% (European Commission, 2022). Consequently, the potential of solar district heating systems is far from being exploited.

A lack of information on the economy of solar-supported district heating systems could be one of the reasons for that. Due to the large number of parameters that have to be taken into account, which are often unknown at the beginning of the planning activities, it is extremely complex to be able to make well-founded statements about the economic viability of a solar-supported district heating systems. Therefore, the latter systems are often ruled out before the actual planning begins. In this work, a sensitivity analysis tool is developed where a comprehensive comparison between solar-supported and conventional district heating systems is carried out.

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2. Methodology

The present tool is designed to quantify the economic efficiency of solar-supported district heating (SDH) systems compared to conventionally operated district heating (CDH) systems. The mentioned comparison is conducted in two principal stages:

1) Calculation of the Levelized Cost of Heat
    a. Calculation of the Levelized Cost of Heat for a SDH system
    b. Calculation of the Levelized Cost of Heat for a CDH system
2) Execution of the sensitivity analysis
    a. Comparison of the Levelized Cost of Heat
    b. Variation of individual parameters for sensitivity analysis

2.1 Calculation of the Levelized Cost of Heat

There are a number of methodologies that can be employed to calculate economic efficiency. To illustrate, there are static methods, such as the static amortization method, and dynamic methods that also consider the timing of incoming and outgoing payments, such as the annuity method or the internal rate of return method (Poggensee & Poggensee, 2021). Due to the large number of options for analyzing economic efficiency, it is often difficult to compare the individual results for different systems, therefore a standardized calculation method is also being sought in the solar thermal sector. In the course of IEA SHC Task 54 "Price reduction of solar thermal systems" the calculation method of "Levelized Cost of Heat" (LCoH) for solar thermal applications was finally introduced. The calculation of LCoH is based on the methodology of the "Levelized Cost of Energy" (Short et al., 1995), which has so far been used mainly in the electricity sector, for example in (Branker et al., 2011; Zakeri & Syri, 2015).

In essence, LCoH describes the capital utilization throughout the service life, divided by the supplied energy. The calculation method of LCoH, used in this work, was formulated within the collaborative work in IEA SHC Task 54 and is given in the equation below (Louvet et al., 2019):

$$LCoH = \frac{I_0 - S_0 + \sum_{t=1}^{T} \frac{C_t(1-TR) - DEP_t \cdot TR}{(1+r)^t} - \frac{RV}{(1+r)^T}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \quad \text{(eq.1)}$$

Where $LCoH$ is the levelized cost of heat (€/kWh), I_0 is the initial investment (€), S_0 are subsidies and incentives (€), T is the period of analysis in year, C_t are operation and maintenance costs (€/a), TR is the corporate tax rate (%), DEP_t and E_t are asset depreciation (€/a) and final energy (kWh/a), RV is the residual value (€) and finally r is the discount rate (%).

In IEA SHC Task 54, a simplified formula was employed for the calculations, as the focus was on small, mainly residential solar thermal systems. For example, interest rates, corporate tax, asset depreciation and the residual value were often set at 0 (Louvet et al., 2019). As district heating systems are predominantly commercial or industrial, the complete formula, including corporate tax rate, asset depreciation and residual value, as outlined in eq.1, is employed for the calculation of LCoH in the course of this work.

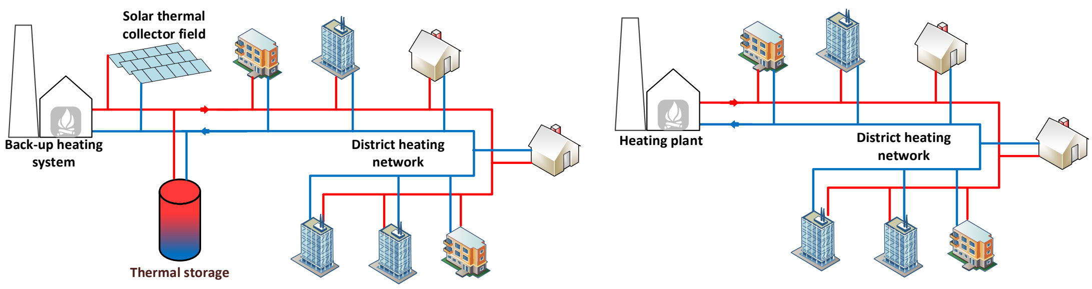

Fig. 1: Definition of solar-supported district heating system with back-up heating system (left) and conventionally heated solar district heating system (right) in scope of this work

As a basis for the sensitivity analysis, the LCoHs are calculated for both SDH and CDH systems. For the definition of the respective systems, see Fig. 1. As SDH generally does not have a solar fraction of 100 %, they require a back-up heating system which provides the remaining energy demand of the district heating system. It should be noted that, in scope of this work, the LCoH of the SDH also includes the costs associated with the supply of the residual energy demand that cannot be met by the solar thermal system.

The procedure for carrying out the calculation of LCoH and sensitivity analysis is shown in Fig. 2. The required main data for the analysis consists of the annual energy quantity of the district heating network, the utilized solar components, the solar energy yield, the heat generator, the energy source used, current energy prices and as well as general data such as the observation period, costs for CO_2-emissions and the corporate tax rate.

The initial step is to enter the annual energy demand of the district heating network. Subsequently, the solar thermal components are selected, including the solar field and thermal energy storage size, as well as type of the collectors and storage to be employed. Once the required solar thermal components have been selected, their investment costs are determined. Either the costs are already known, for example from a project-specific offer, they can be entered directly. However, in the absence of known costs, the costs are estimated using specific cost curves, both for solar thermal collectors, according to (Mauthner, 2016; VDI 3988, 2018) and for thermal energy storages, according to (Mauthner, 2016; Goeke, 2021). As the selection of the solar thermal components is made via drop-down menu, the cost curves are assigned automatically. Consequently, the investment costs are calculated based on the collector field area and thermal energy storage size and the specific costs according to the cost curves.

Fig. 2: Workflow for calculation of the LCoH and sensitivity analysis

Once the investment costs of the solar thermal parts have been calculated, the annual collector field yield is entered according to a simulation. Based on the entered annual energy demand and the annual solar energy yield, the amount of energy that must be provided by the back-up heating system is determined. Subsequently, a back-up heating system is selected. A variety of heat generators are available, including biomass boilers, oil and gas fired boilers or heat pumps. After entering the annual efficiency factor of the selected heat generator, the investment costs of the back-up heating system are calculated.

Next step is to enter the type of heat generator for the CDH system. As CDH systems does not have a solar thermal support, the entire annual energy demand of the district heating network must therefore be provided by the conventional heat source. After entering the investment costs of the conventional heat generator, the costs of energy resources, maintenance and operational costs, the LCoH are calculated in accordance with eq.1.

The LCoH can be calculated for any desired observation period. However, as the individual components, such as the solar thermal collectors or the conventional heat generator, have different estimated lifetimes, this is taken into account via replacement investments and the residual value. The replacement investments and the assumed lifespan of the mentioned components are calculated in accordance with the VDI 2067 "Economic efficiency of building installations – Fundamentals and economic calculation" (VDI 2067, 2012).

2.2 Execution of the sensitivity analysis

The sensitivity analysis includes the calculation of the LCoH, both for SDH and CDH systems, for a variety of scenarios. For each scenario, a selected parameter such as the change in energy prices, costs of CO_2 emissions or a change in investments costs, is altered and the resulting impact on the LCoH is observed. The ratio of the two LCoH (cost ratio = CR) is determined as the key figure for the economic sensitivity analysis (Neyer et al., 2016). The CR is defined as follows:

$$CR = \frac{LCoH_{SDH}}{LCoH_{CDH}} \qquad \text{(eq.2)}$$

Where CR is the Cost Ratio (-), $LCoH_{SDH}$ (€/kWh) is the levelized cost of heat for the solar-supported district heating system and $LCoH_{CDH}$ (€/kWh) is the levelized cost of heat for the conventional operated district heating system.

The CR thus represents the ratio of the LCoH of the two systems under consideration. If the CR is less than 1, the heat generation costs of the SDH system are less than those of the CDH system, indicating a more economical option.

The sensitivity analysis tool calculates the CR based on the entered and defined values. Subsequently, a single specific parameter is altered while all other parameters remain constant, resulting in a recalculation of the LCoH and respectively CR, see Fig. 2. This process is repeated for all defined parameters, and the results are then displayed graphically. This provides a clear visualization of which parameters exert a significant influence on the LCoH and which are negligible. Furthermore, the cumulative costs within the considered observation period of the two analyzed systems are shown graphically.

3. Results

In the following section, the sensitivity analysis tool is employed to assess the feasibility of two different district heating systems in Austria. This includes a consideration of a district heating network in an Austrian city with a planned collector area of almost 44000 m² and a small local district heating network with a collector area of 1590 m². In order to achieve this, the LCoHs are initially recalculated in accordance with the available data and then compared with the published data according to (Becke, 2021; Riebenbauer, 2022). Subsequently, a series of hypothetical scenarios and variants are calculated and a sensitivity analysis is conducted.

3.1 District heating network of an Austrian city

The first project considers the possibility of integrating a large-scale solar thermal system into an urban district heating network. A feasibility study has therefore already been carried out (Riebenbauer, 2022). The feasibility study is used to validate the sensitivity analysis carried out in this work. The selected scenarios and corresponding data required for the calculations are shown in Tab. 1. The objective of scenario A1 is to calculate and compare the LCoH in accordance with the feasibility study that has already been conducted. A1 also serves as a starting point for the subsequent scenarios. In scenario A2, the system considered in scenario A1 is compared with a conventional gas-fired district heating system. In scenario A3, the LCoH is calculated in the event that the solar thermal collector area and the thermal energy storage volume are reduced by 50%.

Tab. 1: Scenarios and given data for sensitivity analysis of a district heating network of an Austrian city

	Scenario A1 (starting point, data according to (Riebenbauer, 2022))	**Scenario A2**	**Scenario A3**
Gross collector area	44847 m²	44847 m²	22424 m²
Collector type	Flat plate	Flat plate	Flat plate
Thermal energy storage volume	2 x 50000 m³	2 x 50000 m³	1 x 50000 m³
Type of back-up heating	Biomass (exits already)	Biomass (wooden chips)	Biomass (wooden chips)
Annual energy demand	27707 MWh/a	27707 MWh/a	27707 MWh/a
Specific solar energy yield	334 kWh/(m²a)	334 kWh/(m²a)	428 kWh/(m²a)
Comparison with	-	Purely gas fired district heating system	Purely biomass fired district heating system (wooden chips)

The values presented in Tab. 1 were integrated into the developed tool and employed for the calculation of the LCoH of the SDH system. The following boundary conditions were established for the calculation:

- Observation period: 20 years
- Discounting factor: 1.035
- Corporate tax: 25%
- Annual efficiency factor for biomass boiler: 0.75 (VDI 3988, 2018)
- Factor for CO_2 emissions natural gas: 0.2008 kg_{CO2}/kWh (Quaschning, 2012)
- Price for biomass (wooden chips): 0.04 €/kWh
- Annual efficiency factor gas-fired boiler: 0.8 (VDI 3988, 2018)
- Price for natural gas: 0.08 €/kWh
- Price for CO_2 emissions: 45 €/t_{CO2}
- Factor for price increase: 1.02

The LCoH for scenario A1 has now been calculated using the shown values and assumptions and the sensitivity of the results is illustrated in Fig. 3. The calculated LCoH is 0.0674 €/kWh, which is markedly lower than the calculated LCoH of the feasibility study (Riebenbauer, 2022), which was 0.0936 €/kWh. One reason for this is the definition of total energy. The LCoH in this tool always refer to the total annual energy required by the district heating network, which consists of the LCoH of the solar thermal part and the LCoH of the back-up heating system. However, the LCoH calculated in (Riebenbauer, 2022) refer only to those of the solar thermal part. Since these are higher than the LCoH of the back-up heating system in this scenario, the LCoH to meet the total annual energy demand must be lower than that of the solar-only part. If only the solar-related LCoH were calculated the resulting costs would be 0.0855 €/kWh. The LCoH for the solar-thermal part only calculated with this tool is therefore within the range of the LCoH calculated in the feasibility study. The small difference can be explained by the different investment costs. The present tool calculates the investment costs on the basis of cost curves. In this scenario, these are likely to be slightly lower than those assumed in the feasibility study. In addition to the costs associated with the energy prices, investment costs for the thermal storage have the most significant impact on heat generation costs, which was also corroborated in (Riebenbauer, 2022).

In scenario A2, a hypothetical comparison is made between a SDH system with a biomass back-up heating system and a gas-fired CDH system. The data from scenario A1 is used as the foundation for this scenario. In both cases, it is assumed that the SDH and the CDH systems are completely new, therefore there is no availability of any of the components at the beginning of the observation period. The economic efficiency of the two systems is evaluated in relation to the CR, as illustrated in (eq.2). The sensitivity of the CR is shown in Fig. 4. It is clearly visible, that the CR with the preselected parameters is already below 1 and therefore the SDH system is already more econmomical than the gas-fired CDH system.

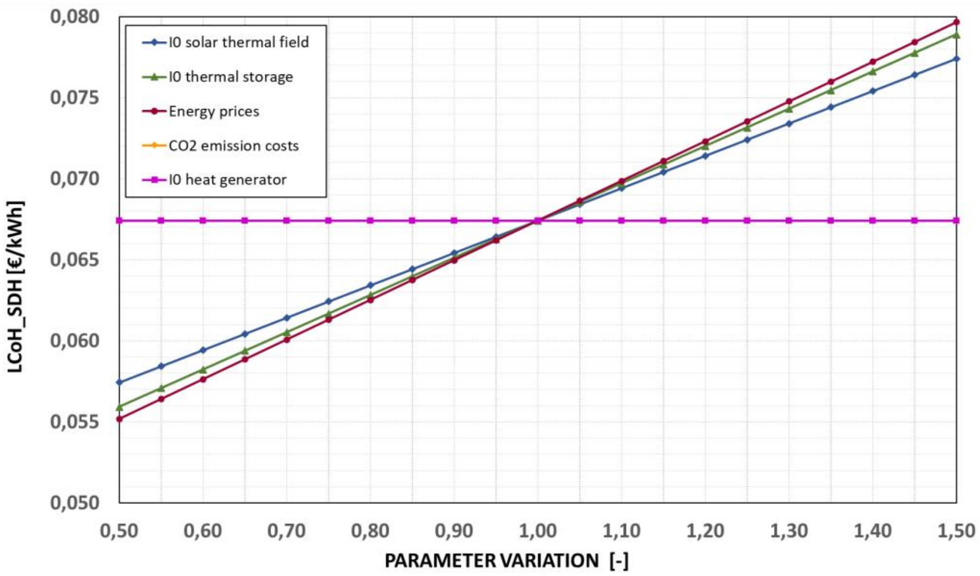

Fig. 3: Sensitivity of the calculated LCoH scenario A1

Moreover, it is evident that fluctuations in energy prices exert the most significant impact on the CR, whereas cost of CO_2-emissions, bases on an assumed value of 45 €/t_{CO2}, exert a comparatively minor influence. In contrast to scenario A1, the necessity of purchasing the biomass and gas-fired boiler has an impact on the CR, as these also require an investment. When considering the impact of investment costs in isolation, it is evident that the thermal energy storage has the most significant effect on the CR.

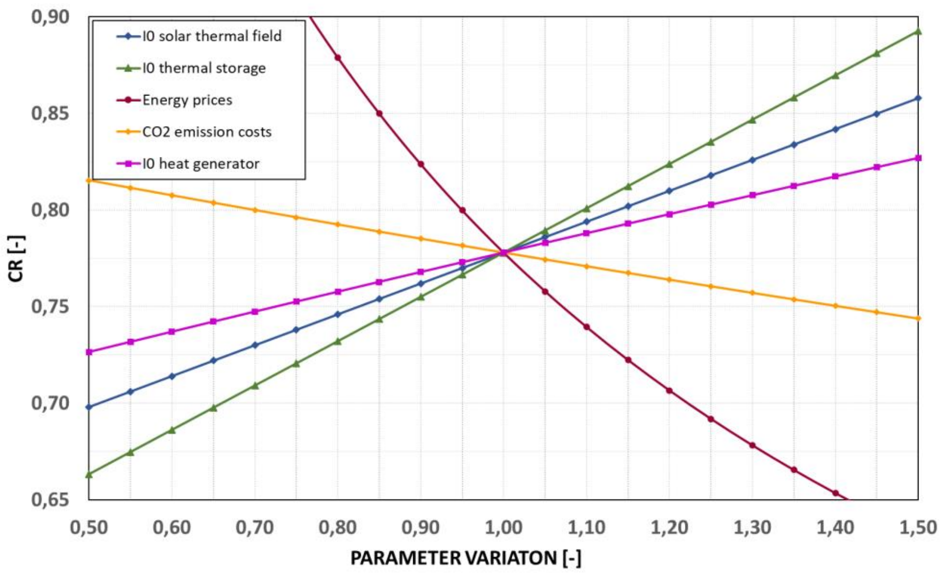

Fig. 4: Sensitivity of the calculated CR scenario A2

In addition to the LCoH and the CR, the cumulative costs are calculated over the observation period, see Fig. 5. As a consequence of the high investment costs associated with the solar thermal components, the SDH system exhibits significantly higher cumulative costs at the outset of the observation period, but after just 12 years the cumulated costs of the SDH system are already lower than those of the gas-fired CDH system. Due to the assumed lifespan of the biomass boiler of 15 years, a replacement investment is necessary. This is also evident in Fig. 5. Despite this replacement investment, when considering an observation period of 20 years, the SDH system is still more economical than the CDH system.

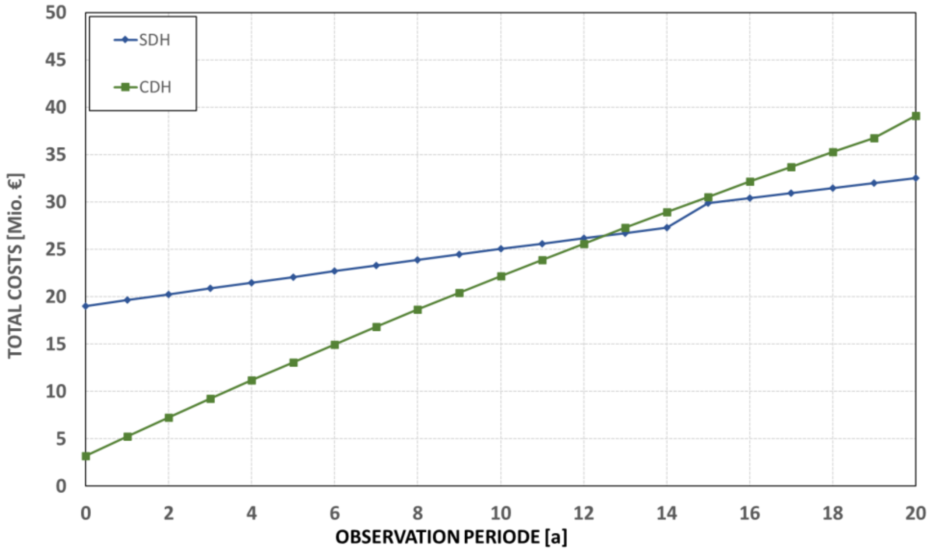

Fig. 5: Cumulative cost scenario A2

In scenario A3, the solar components are each reduced by 50% due to the high investment costs. The SDH system is now being compared with a conventional biomass-fired district heating system. Fig. 6 illustrates the sensitivity of the calculated CR for scenario A3. The calculated LCoH of the SDH system amount to 0.0654 €/kWh and those of the conventional system to 0.063 €/kWh, which results in a CR of 1.035. In (Riebenbauer, 2022), the LCoH was also calculated for the case of a 50% reduction in the solar thermal components. There, the LCoH amounted to 0.0746 €/kWh. However, these heat production costs again only relate to the solar-thermal heat production and not to the annual energy requirement, which needs to be covered. Fig. 6 also illustrates that a price reduction of approximately 20% for the thermal energy storage is sufficient to achieve a CR of 1. This indicates that the SDH and CDH system would have identical heat production costs. A similar outcome would be attained if the energy prices for the fuel were to rise by 15%. In this scenario, the costs associated with CO_2-emissions are not a factor, as both the SDH and CDH system utilize a biomass as energy source.

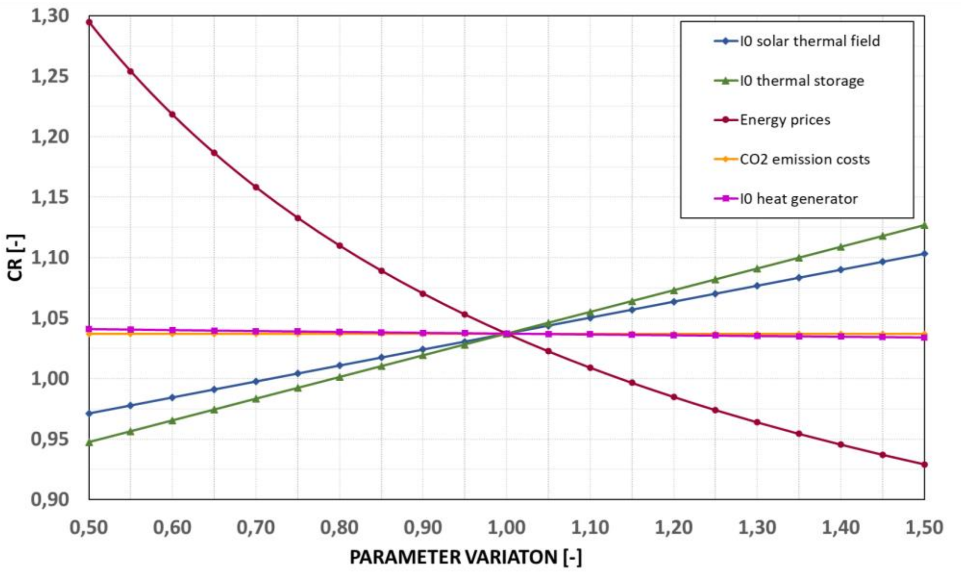

Fig. 6:Sensitivity of the CR scenario A3

3.2 Small local district heating system

In the second project, the developed tool will be applied to a local district heating network. To be able to compare and validate the LCoH of different variants, they are calculated once according to VDI 3988, “Solar thermal process heat” (VDI 3988, 2018) and once with the present tool. Scenario B1 uses the data from (Becke, 2021) to calculate the LCoH. It is assumed that the biomass-fired back-up heating system is already in place. Since this is a real existing system, it is not necessary to use cost curves as an input for the sensitivity analysis, but the known costs can be entered directly. The boundary conditions are the same as for the previous project. The different scenarios are listed below in Tab. 2.

Tab. 2: Scenarios and given data for sensitivity analysis of a local district heating network

	Scenario B1 (starting point, data according to (Becke, 2021))	**Scenario B2**	**Scenario B3**
Gross collector area	1590 m²	1590 m²	1590 m²
Collector type	Double glazed flat plate	Double glazed flat plate	Double glazed flat plate
Thermal energy storage volume	100 m³	100 m³	100 m³
Type of back-up heating	Biomass (exits already)	Biomass (wooden chips)	Biomass (exits already)
Annual energy demand	4509 MWh/a	4509 MWh/a	6493 MWh/a
Specific solar energy yield	458 kWh/(m²a) (simulated)	458 kWh/(m²a) (simulated)	664 kWh/(m²a) (measured)
Comparison with	Purely biomass fired district heating system (exists already)	Purely gas fired district heating system	Purely biomass fired district heating system (exists already)

Scenario B1 represents the realized state, using simulated data. As the CR here is just under 1, the SDH system is more economical that the CDH system, see Fig. 7. This is mainly due to the fuel savings resulting from the use of solar thermal energy. If the costs would decrease by 10% both the SDH and CDH system would have the same heat production costs. The LCoH calculated with the developed tool amount to 0.0504 €/kWh. These costs have been calculated for the SDH system and therefore include the costs of the solar-thermal part as well as the costs of the back-up system. For comparison, LCoH was also calculated according to VDI 3988, “Solar thermal process heat (VDI 3988, 2018). LCoH of 0.0516 €/kWh is specified here. Both calculated LCoH values are therefore in a similar range. If investment costs are considered on their own, the investment costs of the collector field have the greatest influence on the heat production costs in this project, while the thermal energy storage has only an insignificant influence.

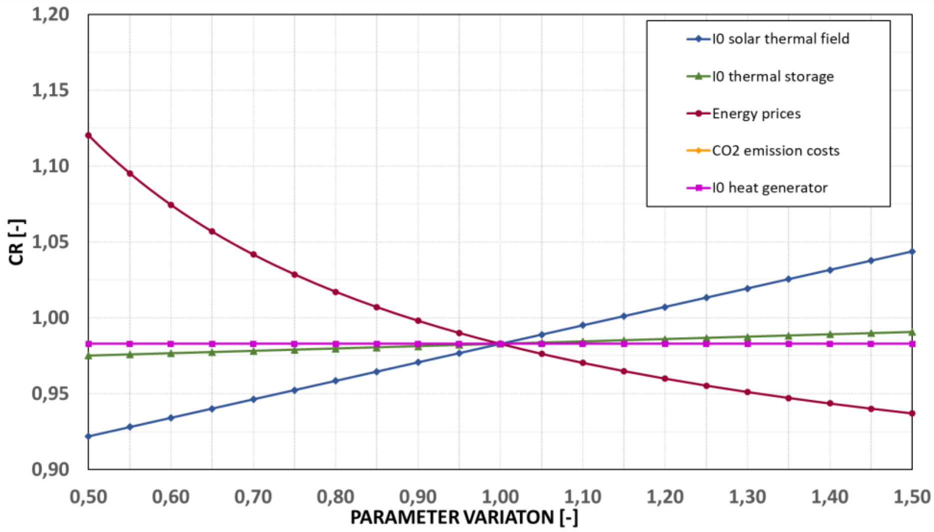

Fig. 7: Sensitivity of the CR of scenario B1

In scenario B2, as in scenario A1, a comparison is made between a SDH system with a biomass back-up heating system and a conventional gas-fired district heating system. In contrast to scenario B1, it is assumed that no heat generators are available yet and therefore all heat generators have to be purchased. The result of the sensitivity analysis of the CR of scenario B2 is shown in Fig. 8. Again, energy prices have the greatest impact on the CR.

Due to the comparison with a gas-fired district heating system, the cost of CO_2-emissions also has a significant impact. Looking only at the investment costs, those for the heat generators have the greatest influence in this scenario, while the investment costs for the thermal energy storage have almost no influence. This is mainly due to the fact that the investment cost of the 100 m³ thermal energy storage is only small part of the total investment cost. The cumulative cost for this project can also be displayed graphically. This is shown in Fig. 9. After just 3 years, the SDH system is already more cost-effective than the CDH system.

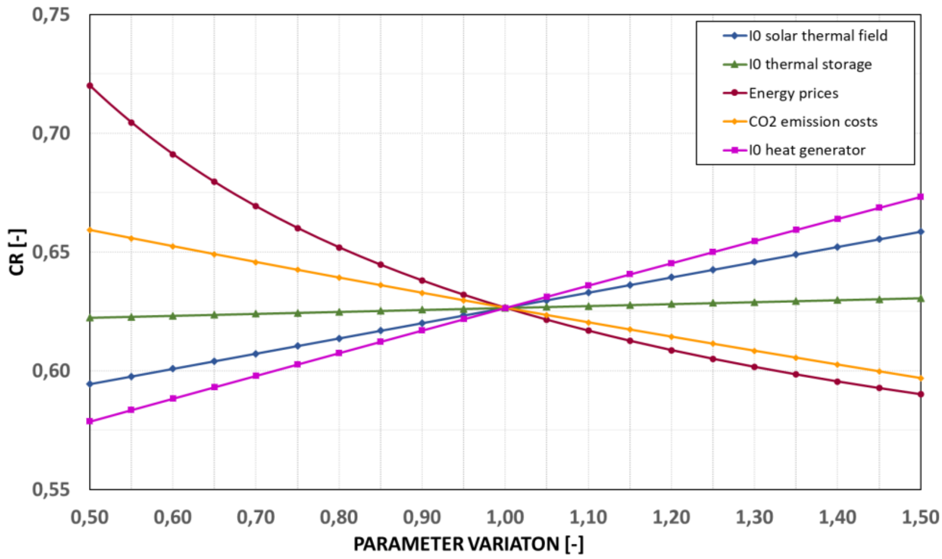

Fig. 8: Sensitivity of the CR scenario B2

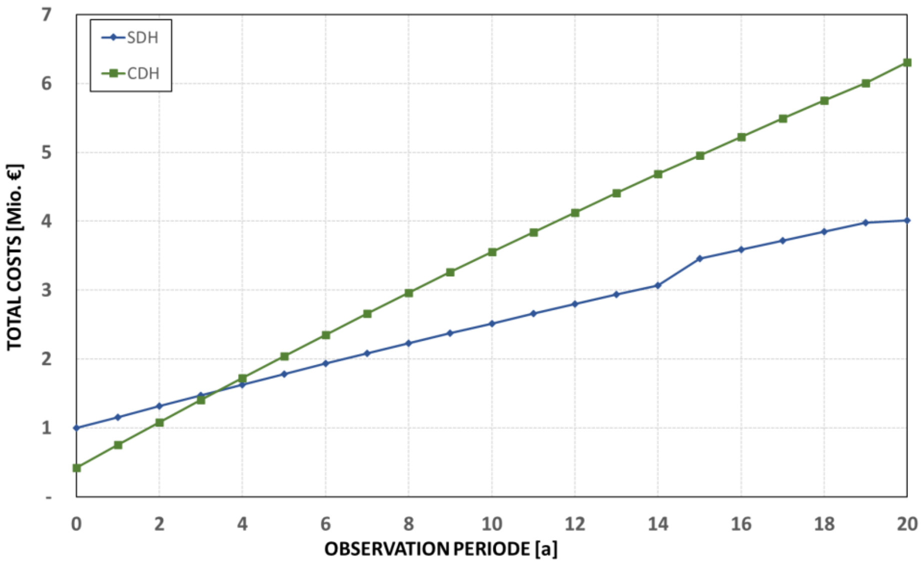

Fig. 9: Cumulative costs of scenario B2

As B1 is a realized project, a sensitivity analysis is conducted in scenario B3 using data collected in accompanying research. While the calculation in scenario B1 was based on simulated data, the sensitivity analysis in scenario B3 employs real measured data. In the simulation, an annual heat demand of 4509 MWh/a was assumed. However, the actual operation of the district heating network demonstrated a total heat demand of 6493 MWh/a. The latter resulted in a specific solar energy yield that was about 45% higher than that assumed in the simulation, as listed in Tab. 2. Subsequently, a sensitivity analysis was conducted for scenario B3 utilizing the measured data. The calculation of the LCoH for the SDH system yields in a value of 0.0482 €/kWh, whereas the costs of 0.0513 €/kWh are recorded for the CDH system. In comparison to scenario B1 there has been a reduction in the LCoH from 0.0504 €/kWh to 0.0482 €/kWh for the SDH system. This is a consequence of an increased annual heat demand and the resulting higher specific solar energy yield. The projected LCoH for the CDH system have been calculated to be 0.0513 €/kWh, which results in a CR of 0.93. The sensitivity of the CR is illustrated in Fig. 10. Scenario B2 exhibits comparable characteristics to that of scenario B1. However, CR is slightly diminished in comparison to that observed in scenario B1, predominantly due to the reduced LCoH of the SDH system.

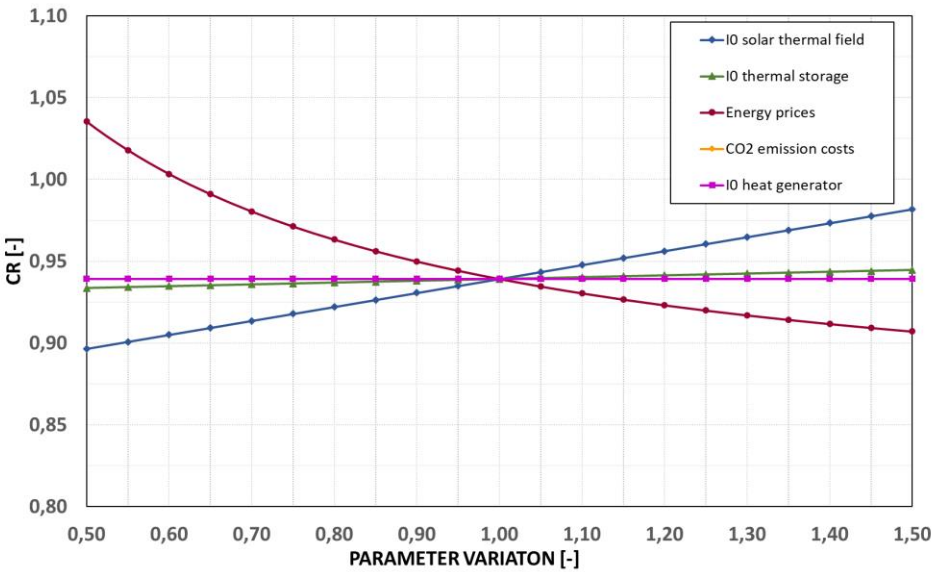

Fig. 10: Sensitivity of the CR scenario B3

3.3 Summary of the calculations performed

Previous chapters demonstrated the applicability of the developed tool in practical settings. Consequently, it is feasible to ascertain the economic viability of SDH systems at the outset of the planning phase. The results of the calculated LCoH and the LCoH from the validation data are listed in Tab. 3. In scenario A1 and scenario A3, it was established that the SDH system is not more cost-effective that the CDH system. This is primarily due to the high investment costs associated with the solar thermal components. In scenario A2, the SDH system would be the more economical option when compared to the CDH system. However, this is only because a conventional gas-fired district heating system was selected as the basis for comparison. A comparison of the LCoH with scenarios A1 and A2 reveals that the highest LCoH is still associated with scenario A2. A comparison of the validation data reveals that the calculated LCoH is markedly lower than those derived from existing validation data. However, this is largely attributable to the fact that the LCoH of the validation data was only calculated for the solar thermal part. Given the significant investment costs associated with these, the LCoH calculated exclusively for the solar thermal part is also considerably higher.

When analyzing the existing local heating network, the LCoH calculated within this work shows a good overlap with the LCoH calculated according to the VDI 3988, “Solar thermal process heat” (VDI 3988, 2018). In scenario B1, it was established that the SDH system is more cost-effective than the CDH system within the specified boundary conditions. This is primarily due to reduction of fuel consumption resulting from the utilization of solar thermal energy. In scenario B2, a further hypothetical comparison of two new systems was conducted. This scenario once more encompasses a SDH system with a biomass back-up boiler and a gas-fired CDH system. As with the previous scenario, the results demonstrated that the SDH system is considerably more cost-effective than the gas-fired district heating system. In scenario B3, actual measured values were employed on the calculation of the LCoH. As a consequence of the increased annual energy demand and the associated increase in the specific solar energy yield, a further reduction in the LCoH was observed in comparison to scenario B1.

Tab. 3: Comparison of the calculated results of the various scenarios and validation data

	Scenario A1	**Scenario A2**	**Scenario A3**	**Scenario B1**	**Scenario B2**	**Scenario B3**
LCoH_SDH (calculated with this tool)	0.0674 €/kWh	0.0767 €/kWh	0.0654 €/kWh	0.0504 €/kWh	0.0609 €/kWh	0.0482 €/kWh
LCoH_CDH (calculated with this tool)	0.0513 €/kWh	0.0986 €/kWh	0.0630 €/kWh	0.0513 €/kWh	0.0972 €/kWh	0.0513 €/kWh
LCoH (purely solar thermal, according to (Riebenbauer, 2022))	0.0936 €/kWh	-	0.0746 €/kWh	-	-	-
LCoH_SDH (according to (VDI 3988, 2018))	-	-	-	0.0516 €/kWh	0.0811 €/kWh	0.0493 €/kWh
LCoH_CDH (according to (VDI 3988, 2018))	-	-	-	0.0533 €/kWh	0.0889 €/kWh	0.0533 €/kWh

4. Conclusion and Outlook

In course of this work, a sensitivity analysis tool was developed with the objective of providing a simple and effective method for the analysis of economic efficiency in solar-supported district heating systems. The basis for the execution of the sensitivity analysis is the calculation of the LCoH. The latter is calculated once for a solar-supported district heating system and once for a conventional district heating system. The comparison of the two systems is carried out using the cost ratio of the LCoH. The essential data required for calculating the LCoH are the solar thermal collector area, the thermal energy storage volume, the annual energy demand of the district heating system and current energy prices. As investments costs for the solar thermal components are often unknown at the beginning of the planning activities, these can be estimated using cost curves provided. However, available project-specific costs can also be entered directly. The LCoH can be calculated for any observation period, as it takes into account replacement investments for solar thermal components and heat generators, as well as their residual values. This allows easy comparison with other methods of calculating LCoH.

In order to validate and verify results from the developed tool, the latter was applied to two different projects. These entailed the evaluation of a potentially solar-supported district heating system in an Austrian city, as well as an assessment of an existing local heating network. Three distinct scenarios were considered for each of the two projects, with scenario 1 representing the status quo as determined by the validation documents. In scenario 2, a hypothetical comparison was made between the construction of a new solar-supported district heating system and conventional gas-fired system. In scenario 3, the sensitivity analysis was carried out for a variation of scenario 1.

In the first project, heat production costs were already calculated as part of a feasibility study. Based on the available data, these were recalculated and compared using this tool. It was found that the heat production costs in the feasibility study were always higher than the costs calculated in this project. This is because the heat production costs in the feasibility study only referred to the solar thermal part, whereas the costs calculated with the present tool always referred to the total annual energy demand. The method used here, therefore also takes into account the cost of the back-up system. As the cost of the back-up is lower than the cost of the solar thermal part in the calculated cases, the calculated heat production costs of the whole system is lower than that of the solar thermal part only. For this reason, the differences that occurred were mainly due to the difference in the methods used to calculate heat production costs.

In the second project, validation was carried out using a comparative calculation with VDI 3988 “Solar thermal process heat”. A very good agreement was found between the calculation of heat production costs carried out according to VDI 3988 and those carried out with the tool at hand. As the second project is a real existing facility, the LCoH was calculated twice. The first calculation was based on the values from the simulation and the second on measured values from the plant. Due to the increase in the annual heat demand of the system and the associated increase in the specific solar energy yield, the LCoH of the measured scenario was again lower than those of the simulation scenario.

Next step is to integrate the effects of the district heating network, e.g. supply and return pipe temperature levels in winter and summer, proportion of summer load and its effect on the annual solar coverage, etc. into the sensitivity analysis tool. Thus, it is possible to consider various settings regarding network operation (especially temperature levels) of the district heating network in the sensitivity analysis.

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