Life cycle impact assessment for a district heating project with seasonal storage

A case study analysis for a community project based in Bracht, Rauschenberg, Hessen, Germany

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1 Abstract

A Life Cycle Impact Assessment (LCIA) was conducted for a solar district heating community project in Bracht, Germany, which incorporates solar thermal collectors, a seasonal heat storage unit powered through an electric heat pump, a supplemental biomass boiler as a backup solution for when there is no heat available from the solar based system, and a transport network to supply residential consumers.

The assessment used standard environmental impact methods to evaluate the system over a 50-year lifetime, based on the energy delivered. Despite supplying the majority of the energy, the solar thermal component contributed less than 15% to the overall environmental impact. Instead, the biomass backup and electricity sourced from the grid accounted for roughly two-thirds of the total impact, even though they provided only one-third of the energy.

The study concludes that while the Bracht system is environmentally favourable compared to many alternatives, further improvements are possible, for example by relying on renewable electric energy for the heat pump and by further minimising heat losses in storage and transport.

2 Introduction and related work

Heating is an important topic for energy consumption since it amounts to roughly half of the consumed energy in the EU. Currently, 60% of that energy is generated from fossil fuels [1]. District heating is a setup where one heating generator plant serves many households connected via pipes. District heating works in two ways: Either to utilise surplus heat from sources such as waste incineration plants for heating purposes in residential areas and service centers [2], or to use a dedicated source of energy, e.g. biomass or solar thermal collectors.

There are 6000 existing district heating systems across the EU [1]. Process heating uses a similar setup but is targeted at industrial purposes, which usually require higher heat temperature. Studies like [3] have shown that using a centralized heating component together with heat transport pipes to reach participating consumers has lower environmental impact compared to standalone heating component for each consumers.

Solar thermal collectors (STCs) are devices that absorb solar radiation and convert it into heat. There are different types of solar thermal collectors, including flat plate solar collectors, unglazed water collectors, and evacuated tube solar collectors. They are combined with heat pumps to bridge the gap between solar field produced water temperature and district heating delivery system required temperature [4]. According to [5], there are more than 300 large scale district heating systems globally that are powered with STCs, and more than 1200 STC systems that provide industrial process heat.

Solar thermal collectors are a mature technology. In 2023, the total operational solar thermal capacity reached 560 GWth, which covers roughly 800 km2 of collector area [5]. STC-provided capacity varies seasonally depending on available sunlight. Sometimes STCs are used only for parts of the year, e.g. to enable turning off a biomass-powered plant in the summer since it would run at extremely low capacity. STCs can be combined with a short term heat storage acting as buffer or a seasonal heat storage tank (e.g. underground hot water basin) to store extra heat from the hot season for the cold season, which incurs heat losses. If space restrictions require such a setup (or if land is cheaper), the geographical location of an STC can be remote from consumers and plants via pipelines (e.g., 4 km in Priština [1]). However, there is a trade-off since the remote location required laying the necessary pipes underground.

In scientific literature, a small number of LCIA case studies for district heating systems exist, e.g. for the systems in Milan [6] and Marseille [7]. Life Cycle Impact Assessment, in particular the based on the ReCiPe method, has been used to assess the environmental impact of different STC powered district heating configurations by [8]. The outcome was that larger systems that serve many households have a lower environmental impact per energy unit served. In [9], the authors provide an LCIA study of a STC plant connected to the Geneva district heat network and find that there is no LCI data available for the coupling of large scale solar thermal installations and district heating networks, and provide suggested numbers that could be used to complement district heat production routes.

For the community district heating project in Bracht, the economic viability in comparison to conventional energetic renovation measures has been assessed in a previous study ([10]). However, the environmental impact of the project has not yet been examined in detail. This gap forms the focus of the present study.

3 Methodology and research questions

The foreground data was collected from various online sources and combined with background data from the Ecoinvent v3 database [11] and from the UVEK LCI database version DQRv2:2025 [12]. The environmental impacts were assessed using the mid-point level Environmental Footprint (EF) method [13], and the Ecological Scarcity 2021 v1.04 method [14] at the single score level with UVEK LCI weighting set. The LCIA was performed using the SimaPro 9.6.0.1 software [15].

The research questions were formulated as follows:

1. What is the relevance of the additional electricity required in the setup (amounting to 6% of overall energy consumed) and the supplemental biomass boiler (amounting to 26% of overall energy consumed) with respect to the overall environmental impact? The hypothesis is that the additional electricity and biomass required will amount to a sizable part of the overall environmental impact.
2. How does the STC based system with seasonal heat storage compare to other heating technologies in terms of environmental impact? The comparison will include district heating from other sources that would be available in small communities (such as a heat pump or wood chips), and consumer side heating installations such as oil or gas boilers. The hypothesis is that the STC based system will have a lower environmental impact compared to other district heating setups and to fossil energy based consumer installations.
3. What is the environmental impact contribution of the seasonal heat storage unit in the production, construction, and use stages in the life cycle? A sensitivity analysis will be performance to assess the benefits of the STC based system with a seasonal heat storage component included under several assumed loss coefficients for the storage component and the transport pipes system. The hypothesis is that the seasonal storage component will lower the environmental impact.

4 Goal and scope

The goal and scope definition is a fundamental step in any Life Cycle Impact Assessment (LCIA), as it provides a clear description of the product system under study, its system boundaries, and the definition of a functional unit that reflects the output of the system in a consistent and measurable way. This section outlines the specific goal and scope of the LCIA conducted for the district heating project described in this document.

The focus of the given assessment is a district heating project that has been initiated and is operated by a cooperative consisting of both future household consumers and the local municipal council. The system as despicted in Figure 1 includes the following key components:

- solar thermal collector (STC) field,
- seasonal storage unit (SSU), sometimes referred to as Pit Thermal Energy Storage (PTES),
- heat preparation (HP) component with heat pump powered by electricity from the grid, buffer storage unit, biomass combustion unit serving as a backup heat source when stored heat is unavailable,
- heat transport (HT) distribution network that supplies heat to residential consumers, and
- receiver units installed in each participating household.

There are at least 180 consumer households expected, which is roughly 60% of all households that exist in the local community.

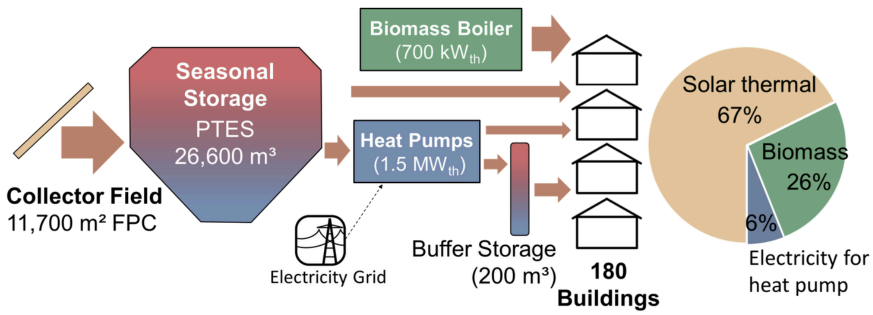

Figure 1: System overview for the Bracht community district heating network. (Source: University of Kassel)

The functional unit is defined to be 1 MegaJoule (MJ) of thermal energy provided to the consumer directly at the consumer site during the heating period. Using MJ instead of kilowatt-hours of thermal energy (kWh_{th}) ensures consistency with the UVEK processes for other forms of district heating in SimaPro that the comparison will be performed against.

The lifetime of the district heating system is assumed to be 50 years. The system diagram shown in Figure 2 describes the product system and its boundaries.

5 Life Cycle Inventory (LCI)

This section outlines the foundational data used to support system modelling. Extensive project-related information for the Bracht community district heating system is available on the project website [16]. This was used extensively as a key source for detailed LCI data. It provided detailed data on the solar thermal collector field, the seasonal storage unit, and heat preparation systems comprising the heat pump, buffer storage, installation facility, and consumer installations.

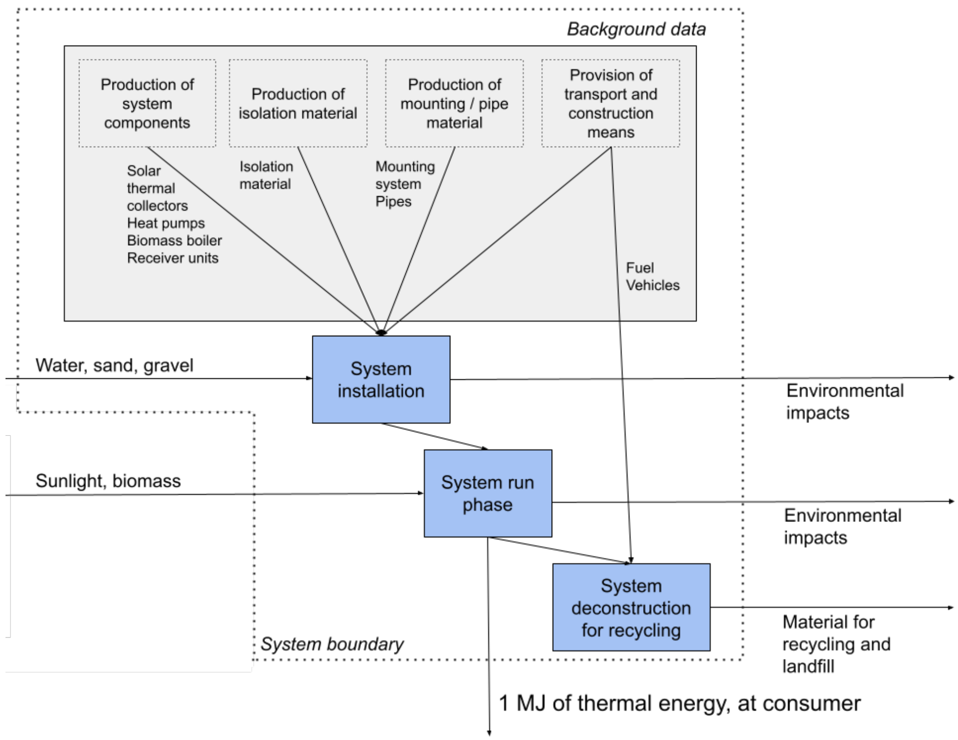

Figure 2: System diagram for the Bracht community district heating network, with functional unit as stated.

The comparison datasets and the heat transport network were modelled based on UVEK LCI data [12], an existing resource for conducting LCIAs of energy systems and infrastructure within Switzerland and the broader European context provided by the Swiss Federal Office of Energy (abbreviated in English as SFOE, and in German as UVEK). For electricity input, the modelling assumed the European Network of Transmission System Operators for Electricity (ENTSO-E) production mix, also provided in the UVEK dataset, to ensure the model reflects conditions typical of a plant operating within the European region.

Additional LCI details for all components are provided in Section 9.1. Detailed specifications and parameters of the resulting system model are described in Section 9.2. The remainder of this section outlines the key assumptions regarding component lifetimes, expected electricity demand, and thermal loss coefficients.

5.1 Component lifetimes

The planned lifetime for the Bracht plant is 50 years. The assumed individual component lifetimes and the resulting relevant multipliers are shown in Table 1. The assumed individual component lifetimes are in line with the assumptions used in [17].

Table 1

Component	Years	Multiplier	Source
Solar thermal collectors	30	1.67	[18]
Seasonal storage unit	30	1.67	[17]
Heat pumps	20	2.5	[19]
Heat buffer storage	20	2.5	[18]
Heat installation facility	50	1	[20]
Heat exchange stations at consumer	20	2.5	[17]
Heat transport network	50	1	[17]

5.2 Electrical power requirements and loss coefficient assumptions

Performance data from [21] provides several estimates of the annual output for the solar thermal collectors used in this project. These estimates vary by geographic location and desired output temperature. The most geographically relevant data point is for Würzburg, with an output of 5.283 kWh per collector per year at a target output temperature of 75 degrees Celsius (°C). Given a total of 855 collectors, the estimated gross thermal energy production is approximately 4.517 MWh per year.

According to the project documentation [22], 2.700 MWh per year are expected to reach end-user households. This implies a total system loss of approximately 40%, accounting for thermal losses in the storage unit and distribution piping.

The energy distribution for heating supply is reported in Figure 1 as follows:

- 67 % from stored solar thermal energy (approximately 2.258 MWh),
- 26 % from biomass sources (approximately 904 MWh), and
- 6 % from the electricity grid (approximately 209 MWh)

Since detailed methods for the loss estimates used in the Bracht assumptions are not provided in the public documentation, the modelling described in this document assumes a 20% loss coefficient as the default for the heat transmission pipe network. The relevant literature and further rationale for the choice are presented in @Section 7.3.1. Given this assumption, the implied thermal loss within the seasonal storage unit would be approximately 50% to align with the reported figures from [22]. These assumptions were incorporated into the system model as the default values. More background and a detailed discussion of thermal loss coefficients and their influence on system performance is presented in the sensitivity analysis in Section 7.3.

6 Results

The system model, as detailed in Section 9.2, was implemented using SimaPro [15]. This model served as the foundation for generating LCIA results using the Environmental Footprint (EF) method [13] and the Ecological Scarcity 2021 v1.04 method [14]. The corresponding results derived from these assessments are presented in this section.

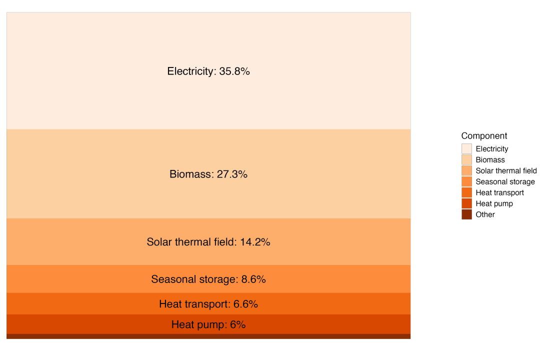

Figure 3: Relative environmental impact of Bracht community district heating system components (Ecological Scarcity 2021, v1.04, UVEK LCI weighting)

To address the first research question regarding the environmental impact of the additional electricity and the supplemental biomass burnt in the wood boiler, the relative influence of the individual components of the solar thermal district heating system on overall environmental impact was evaluated using the Ecological Scarcity 2021 (version 1.04) method. The assessment was conducted at the single-score level, applying the UVEK LCI weighting set to define the relative importance of the different damage categories. The results are presented in Figure 3. They show that the biomass (27.3 %) and the electricity (35.8 %) together have a very large impact. They are responsible for nearly two-thirds of the environmental impact of the overall system. The solar thermal based part of the system with solar thermal field, seasonal storage, and heat pump is responsible for less than 30 % of the overall environmental impact, although they supply two-thirds of the total energy production (see Figure 1). Only one-third of the energy delivered to end consumers originates from the biomass and electricity.

Figure 4: Relative environmental impact of Bracht community district heating network system components (Environmental Footprint Method)

For a more detailed view of the environmental impact by individual damage categories, Figure 4 presents the drilled-down individual results for the most relevant impact categories *Climate change*, *Particulate matter*, *Eutrophication (marine)*, *Land use*, *Resource use (minerals and metals)*, and *Resource use (fossils)*. The figure shows that biomass combustion is the dominant contributor to Land use, Particulate matter, and Marine eutrophication. In contrast, electricity use is the primary driver of impacts in *Fossil resource use* and *Climate change*. The environmental impact in the *Minerals and metals resource use* category is most significantly influenced by heat preparation and the solar thermal collectors. The seasonal storage unit contributes notably to the *Climate change* category.

In summary, electricity and biomass used to operate and supplement the system are the primary contributors to the overall environmental impact. Electricity consumption is unavoidable due to the operation of the heat pump. However, its impact can potentially be mitigated by sourcing electricity from renewable sources instead of the ENTSO-E production mix (as described in Section 5), an option explored in more detail in Section 7.2. Strategies to reduce biomass consumption by improving thermal efficiency, such as lowering heat loss coefficients, are examined in Section 7.3.

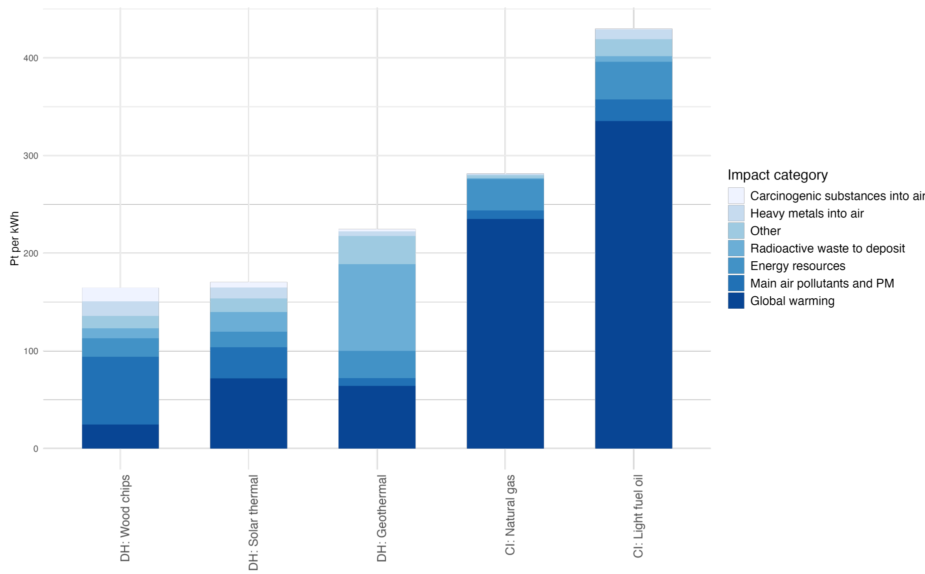

Figure 5: Comparison of environmental impact of Bracht community district heating network to other energy sources for district heating such as wood chips and heat pump, and to consumer installations such as gas and oil burners (Ecological Scarcity 2021, v1.04, UVEK LCI weighting)

To address the second research question, the environmental impact of heat generated by the solar thermal collector based district heating system with seasonal heat storage was compared to that of other heating technologies. The results, presented in Figure 5, show a comparison of the environmental impacts of STC-based district heating with other district heating (DH) options commonly available in small communities, such as systems powered by wood chips (biomass) or geothermal heat pumps. Additionally, the analysis includes consumer-side heating installations (CI), such as oil and gas boilers. The assessment was conducted using the Ecological Scarcity 2021 (v1.04) method at the single-score level, applying the UVEK LCI weighting set. Results are expressed in environmental impact points (Pt) per kilowatt-hour (kWh) of heat delivered.

The result is that the heat produced by the Bracht plant with 170 Pt per kWh of heat shows the second lowest environmental impact compared to the other heating technologies. The largest contributor is the "Global warming" category, dominantly caused by the electricity required (ENTSO-E production mix as discussed in Section 5) and to a lesser extent by the seasonal storage unit and the solar thermal collectors (cf. Figure 4).

The results indicate that heat produced by the Bracht plant, with an environmental impact of approximately 170 Pt per kilowatt-hour, exhibits the second lowest impact among the heating technologies assessed. The dominant contributor to this impact is the *Global warming* category, primarily driven by electricity consumption, based on the ENTSO-E production mix as detailed in Section 5, and to a lesser extent by the seasonal storage unit and the solar thermal collectors (see Figure 4).

The lowest environmental impact with 165 Pt per kWh of heat is returned for the district heating system based on wood chips as the energy source, even with the impact on main air pollutants and particulate matter (PM) having a significant impact on the overall results for this setup. The district heating system based on a geothermal heat pump as the energy source has the third lowest impact with 225 Pt per kWh of heat, to the largest extent from impact on radioactive waste to deposit. Oil and gas based consumer installations fare worse with 430 Pt and 281 Pt per kWh of heat, dominantly from impact on climate change.

As before, Figure 6 presents the individual results for the most relevant damage categories, comparing them relative to the highest value in each category, which is shown as the longest bar representing 100% relative impact. This analysis confirms the findings from Figure 5, clearly demonstrating that oil and gas boilers have extremely high impacts in the *Climate change* category which is equivalent to Global warming in the Ecological Scarcity method with relative impacts of 100% and 70%, respectively. Additionally, oil and gas boilers exhibit the highest fossil resource use, at 100% and 80%.

A clear trade-off exists because each heating technology performs worst in different impact categories. For example, the district heating network using wood chips shows lower climate change impacts but the highest relative impacts in *Marine eutrophication*, *Land use*, and *Particulate matter* (PM). While PM impact was visible in Figure 5, *Marine eutrophication* and *Land use* impacts were not significant in the single score results. Similarly, solar thermal and geothermal-based district heating systems have the highest relative impacts in Minerals and metals resource use, at 100% and 83%, respectively. These trade-offs imply that selecting a heating technology depends on which environmental impacts are prioritized for a given use case. This highlights the need to weigh and balance different categories manually, or to rely on a single score method if applicable.

7 Interpretation and discussion

This chapter discusses the results introduced in Section 6. They revealed that the district heating system based on solar thermal energy and seasonal storage compares favorably to other means of heating. However, in the given modelling, with limitations as documented in Section 7.1, it exhibits higher environmental impact compared to the district heating system based on wood chips as the energy sources. The electricity and the supplemental biomass required were found to be the two top single contributors to the overall results. To understand the saving potential from using lower-emitting (see Section 7.2) or less energy resources (see third research question and Section 7.3), sensitivity analyses for source of electricity and

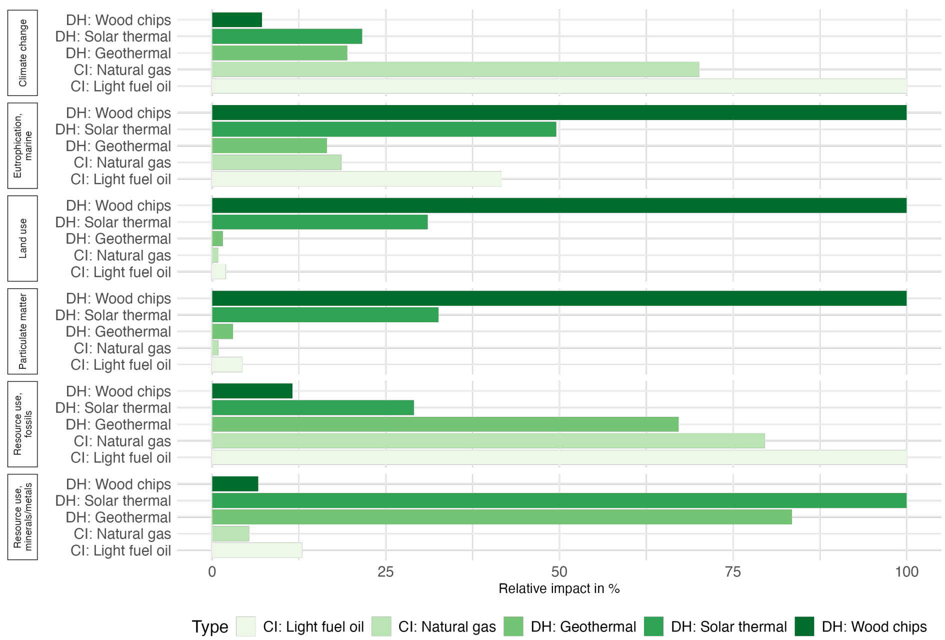

Figure 6: Damage assessment using the Environmental Footprint Method, visualized as relative environmental impacts in comparison.

loss coefficients for the heat loss in the seasonal storage unit and the transport pipes will be performed.

7.1 Modeling limitations

The UVEK data for the other energy sources for district heating (wood chips, heat pump) used an 11 % assumption which means that the solar thermal data with the 20% assumption as mentioned in Section 5.2 is disadvantaged in the comparison in Figure 5. The effect of these assumptions on the results will be investigated in Section 7.3.

Data availability was generally satisfactory with one notable exception for the modelling of the heat pumps used in the system (see Section 9.1.3 for specifications). There are two heat pumps with 630 kW max electrical input power each used in the system, but in the UVEK data, the largest sized heat pump available has a maximum of 50 kW power. The best possible assumption in this situation was that the two large heat pump have the same impact as 25 units of the 50 kW heat pump, but this is likely leading an overestimation of the resource use for minerals and metals. This is acceptable since with 6.1 %, the heat preparation system which includes the heat pump showed only minor impact on the overall results (see **?@fig-network-pie**).

Worth mentioning is that the UVEK data for the transport system district heat has a lifetime assumption of 30 years whereas the Bracht setup assumes 50 years. This is acceptable since with 6.6 %, the heat transport system showed only minor impact on the overall results (see **?@fig-network-pie**).

Note that there was a problem with the weights for the damage category *Water resources, net balance* in the UVEK LCI weighting set that required excluding this category from the analysis.

System deconstruction was modelled for the major infrastructure components, specifically the solar thermal collector field and the seasonal storage unit. The model includes the disposal of plastic materials used for sealing and insulation in the seasonal storage unit, assuming treatment via municipal waste incineration. For the remaining system components only deconstruction processes were included in the model. Final disposal or material recovery for these components was not considered within the scope of this analysis (also see Figure 2).

7.2 Sensitivity analysis: Source of electricity

Figure 5 has shown that the dominant environmental impact is from electricity. For the default mode, the Electricity (ENTSO-E) production mix [12] was assumed. It was also assumed that the production mix will stay the same over the next 50 years, which is not realistic given the net zero by 2050 plans of the European Union. Surprisingly, no

In this section, the potential savings by using lower-emitting electricity are assessed. Since the electricity is required during the winter months where it is much harder to produce compared to the summer months, the relevant UVEK-supplied data for running storage pumps in Austria, Germany, France, Italy, and Switzerland were used for the analysis. The results are shown in Figure 7.

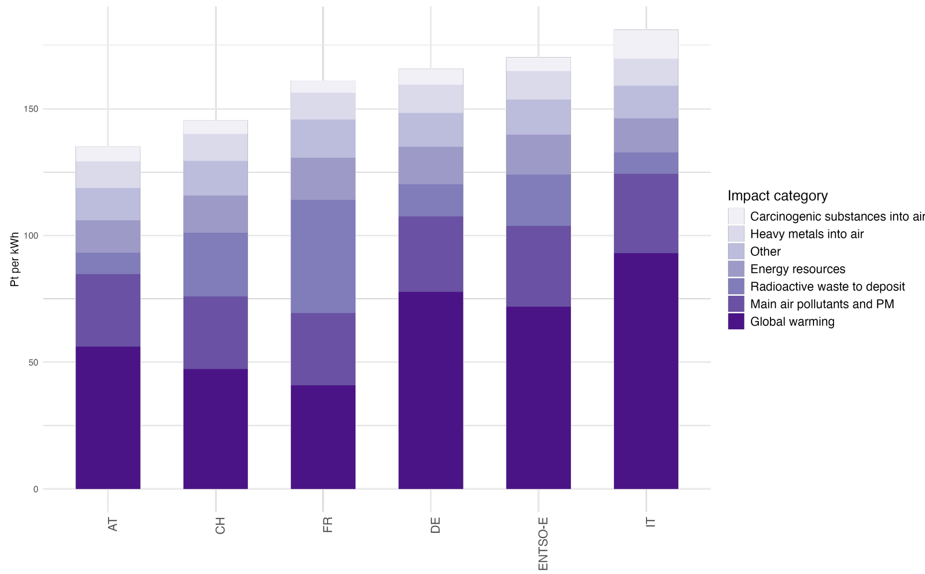

Figure 7: Comparison of environmental impact depending on source of electricity, using UVEK-supplied data for running storage pumps in Austria, Germany, France, Italy, and Switzerland in winter. This analysis is based on the Ecological Scarcity 2021 v1.04 method at the single score level, with UVEK LCI weighting set.

7.3 Sensitivity analysis: Loss coefficients

Heat is harder to transport than electrical power since even good insulation cannot avoid losses of radiating heat. There are two main areas where heat losses occur in the setup: in the pipes, and in the seasonal storage unit. Therefore, the loss coefficients assumed for the pipes and for the storage unit are highly relevant to the modelling.

7.3.1 Pipe heat loss

As summarized in [23], the key parameters affecting heat loss in district heating pipes include the length of the network which depends on the transmission distance relative to demand, the system age, and the operating temperature. The relevant heat loss coefficients reported range between 5 % and 35 %. The Bracht setup involves a relatively long transmission distance of

8800 meters due to its rural context. The planned supply temperature of 85 degrees °C is relatively high and will contribute to increased thermal losses. In contrast, modern district heating systems can operate with lower supply temperatures between 50 and 70 degrees °C to minimize heat loss and improve efficiency as noted by **lund2020districtheating?**.

The rationale behind selecting a default heat loss rate of 20 % for the Bracht setup reflects the combined negative impact of the long transmission distance and high operating temperature on system performance. However, several sources assume lower loss rates. For example, the open source Energy Transition Model [24] suggests a 15 % default loss figure based on real world data for modern district heating networks. The Swiss Federal Office of Energy UVEK assumes an even lower rate of approximately 11 % in its district heating data.

If the Bracht system were optimized to achieve heat loss rates comparable to the UVEK assumption by lowering the operating temperature, annual efficiency gains of about 300 MWh could be realized currently. This would remove parts of the every requirements planned to be supplied via biomass. This would correspond to a roughly 9 % reduction in ecological impact from 170 Pt per kWh to 155 Pt per kWh of heat produced according to the Ecological Scarcity 2021 version 1.04 method at the single score level with UVEK LCI weighting. The most significant reductions were observed in the *Main air pollutants and Particulate Matter (PM)* category, primarily due to the reduced combustion of biomass.

7.3.2 Seasonal storage unit heat loss

In [25], the authors report a 26% loss of heat production in the storage unit amounted to of heat production. The Energy Transition Model [24] suggests 30% as a sensible default for modelling heat loss in the storage unit. Another study [26] provides a comprehensive review and finds that 30% to 50% heat loss are common for Pit Thermal Energy Storage and that the majority of losses are caused by floating cover.

Given these reference numbers from literature, the 50% loss assumption for Bracht is on the conservative side. For the sensitivity analysis, the assumption made is that it can be lowered to 30% based on two different scenarios: (1) without any changes in the setup but an understanding that the original assumptions were not accurate, and (2) by using twice the cover for the top of seasonal storage unit and therefore better insulation. The sides and the bottom of the seasonal storage unit remain unchanged.

In both scenarios, a higher amount of energy is supplied from the seasonal storage unit (3.160 MWh). That consequently results in an increase of electrical energy requirements for the heat pump. A rough estimate of the heightened energy requirements was performed based on using the same factor between energy from the seasonal storage unit and energy from electricity as in the original assumptions (see Section 5.2): 209 MWh divided by 2.258 MWh, which returns a 9 % electricity requirement factor. This results in a 293 MWh electricity demand for the heat pump. With an assumed 20% heat loss in the pipes as in the default assumptions, a remaining amount of 2.764 MWh of energy is available for consumers. This meets the consumer heating demands of 2.700 MWh and therefore, no supplemental energy from biomass is required.

For scenario *(1 - no changes)*, a 15 % reduction from 170 Pt per kWh of heat to 146 Pt per kWh of heat can be achieved. For scenario *(2 - double cover)*, a 9 % reduction to 155[1] Pt per kWh of heat can be achieved.

8 Summary and conclusion

A Life Cycle Impact Assessment was conducted for a solar district heating community project located in Bracht, Rauschenberg, Germany. This project combines solar thermal collectors with a seasonal storage unit to preserve heat produced in summer until the heating period in fall and winter. A heat transport network supplies the thermal energy to 180 residential consumers. The system's energy supply is expected to be 67% from stored solar thermal energy, 26% from biomass, and 6% from the electricity grid. Default modelling assumptions included a 20% heat loss coefficient for the transport network and an implied 50% loss for the seasonal storage unit.

Results indicate that biomass and grid electricity are the primary contributors to the overall environmental impact, accounting for approximately two-thirds of the total, despite supplying only one-third of the energy delivered. The solar thermal collectors contribute less than 15% to the overall environmental impact. Analysis by damage categories shows biomass combustion significantly contributes to Land use, Particulate matter, and Marine eutrophication, while electricity use is the main driver for Fossil resource use and Climate change.

Comparing the Bracht system to other heating technologies, the STC-based district heating system with seasonal storage shows the second lowest environmental impact at approximately 170 Pt per kilowatt-hour (kWh) of heat, based on the Ecological Scarcity 2021 single score method. This is slightly higher than district heating using wood chips (165 Pt/kWh), but significantly lower than a geothermal heat pump district heating system (225 Pt/kWh), oil boilers (430 Pt/kWh), and gas boilers (281 Pt/kWh).

Sensitivity analyses were performed to demonstrate the effects of uncertaunties in input data and the potential for reducing environmental impact. Sourcing lower-emitting electricity could mitigate the impact driven by the grid mix. Furthermore, improving heat loss coefficients, particularly reducing the significant heat loss in the seasonal storage unit to a potentially achievable 30%, could allow the system to meet consumer demand without supplemental biomass, leading to a substantial impact reduction of 15 % in the best scenario.

[1] This is coincidentally the same result as in Section 7.3.1.

The conclusion is that while the Bracht solar district heating system favorably compares to many conventional and alternative heating technologies in terms of environmental impact, further improvements are possible to achieve even lower environmental impact.

Recommendations include using renewable electric energy for the heat pump, and reducing heat losses in storage and transport to minimise, or even completely eliminate, the need for supplemental biomass.

9 Supporting information

This section documents the supporting information related to the life cycle inventory in Section 9.1, the exact data used for process modelling in SimaPro in Section 9.2, and the project organization in Section 9.3.

9.1 Life Cycle Inventory

There are several components described in the following sections: solar thermal collector, seasonal storage unit, and heat preparation.

9.1.1 Solar thermal collector (STC)

The relevant data for the solar thermal collector can be found in Table 2.

Table 2

Dimension	Value	Source
Size	11'638 m^2 (855 x 13.6 m^2)	[27]
Type	Flat-plate collectors Vitosol 100-F XF13 Viessmann	[27] [28] [21]
Land use	23.500 m^2	[27]
Mounting infrastructure material	15 t steel	[16]
Collector weight	50 kg / m^2	Own assumption
Production country	China	Own assumption
Transport per container ship	8000 km	Own assumption
Transport per lorry	1000 km	Own assumption

9.1.2 Seasonal storage unit (SSU)

The relevant data for the seasonal storage unit can be found in Table 3. A picture of the floating cover can be found in Figure 8.

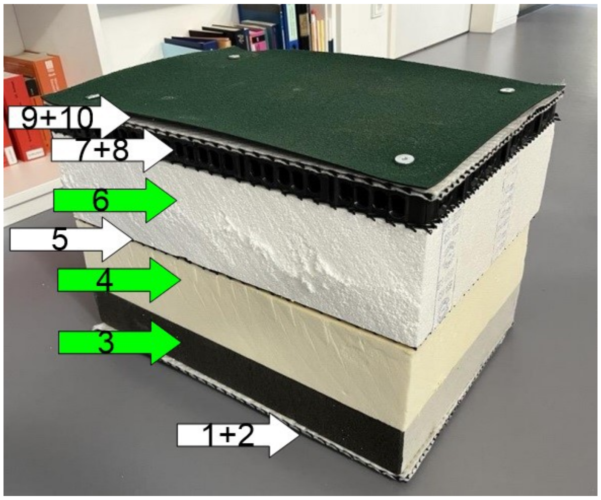

Figure 8: Floating cover profile. Source: Bracht community.

Table 3

Dimension	Value	Source
Volume	26'600 m^3	Figure 1
Resource: water	26'600 m^3 filled from local source	[29]
Cover layer 1, 10	Polyethylen (HDPE) sealing membranes 1.5 mm, 1.5 kg / m^2	[29], estimated weight
Cover layer 2, 9	Fleece (0.1 kg / m^2) laminated plastic grid (HDPE, 0.5 kg / m^2)	[29], estimated weight
Cover layer 3	Foam glass, 8.33 kg / m^2	[29]
Cover layer 4	Polyurethane (bauder foam): 3.125 kg / $m2$	[29]
Cover layer 5, 7, 8	Airing gap made of plastic grid, 0.5 kg / m^2 each	[29], estimated weight
Cover layer 6	Polystyrene (XPS), 3 kg / m^2	[29]
Floating cover dimensions	70 m x 70 m = 4900 m^2	[30]
Floating cover weight	2 * (1.5 + 0.1 + 0.5) + 8.33 + 3.125 + 1.5 + 3 = 20.155 kg / m^2	Calculation
Ground liner	Polyethylen (HDPE), 2.5mm, 2.5 kg / m^2	[29], estimated weight

Dimension	Value	Source
Ground liner dimensions	Bottom 20 m x 20 m, vertical height 15 m, surface area on each of the four sides 5250 m^2	[30]
Ground liner weight	2.5 kg / m^2	Assumption
Production country	China	Assumption
Transport per container ship	8000 km	Assumption
Transport per lorry	1000 km	Assumption
Required construction process	Excavator 26.600 m^3	Figure 1

9.1.3 Heat preparation (HP)

The relevant data for the heat preparation unit can be found in Table 4.

Table 4

Dimension	Value	Source
Heat pump	2x Carrier Aquaforce 61XWH-ZE (630 kW max electrical input power)	[27] [31]
Electricity requirements	209 MWh per year	Own calculation, see Section 5.2
Buffer storage	ca. 200 m^3 = 200'000 l	Figure 1
Biomass boiler	Mawera boiler with 700 kW thermal power	[27]
Controller	Vitocontrol 200-M	[27] [32]
Heat installation facility	50 m^2	Own assumption

9.2 SimaPro Data

Table 5 and Table 6 show the parameters and calculated parameters that were defined as helpers for modelling the solar thermal based district heating process in Simpapro.

The data for the process *district heat, at consumer, solar thermal, 1MW/MJ/RER U* is kept in an external spreadsheet accessible here.

Table 5

Name	Value	Comment
Plant-size-m2	23500	The total size of the plant in sqm
STC-size-m2	11638	The total size of the STC panels in sqm
STC-weight-per-m2	50	The weight of the STC per sqm
STC-prod-MWh-per-a	2700	Production from the STC per year in MWh
Lifetime	50	The lifetime of the plant in years
MWhtoMJ	3600	Conversion from MWh to MJ
Mult30To50	1.67	Multiplier for components with 30 years lifetime
Mult20To50	2.5	Multiplier for components with 20 years lifetime
SSU-volume-m3	26600	The volume of the SSU
SSU-top-m2	4900	The size of the SSU at the top (floating cover) in sqm
SSU-side-m2	5250	The size of the SSU at each of the four sides in sqm
SSU-bottom-m2	5400	The size of the SSU at the ground in sqm
Steel-kg	15000	The weight of the required steel for the STC foundation
Freight-ship-dist-km	8000	The transport distance per freight ship in km
Lorry-dist-km	1000	The transport distance per lorry in km

Table 6

Name	Value	Comment
STC-prod-MJ-lifetime	STC-prod-MWh-per-a * Lifetime * MWhtoMJ	The total production from the STC over the plant lifetime in MJ
STC-weight-t-total	(STC-size-m2 * STC-weight-per-m2 * Mult30To50 + Steel-kg) / 1000	The total transport weight of the STC over the plant lifetime in tons
SSU-ground-m2	SSU-bottom-m2 + 4 * SSU-side-m2	The total size of the SSU that is touching the ground on the bottom and sides in sqm

For the comparison, the following SimaPro processes were employed (all of them part of the UVEK dataset):

- *district heat, at consumer, borehole heat pump, 50kW/MJ/CH U*
- *district heat, at consumer, wood chips in industrial furnace, 1MW/MJ/CH U*
- *heat, light fuel oil, at boiler 10kW, average/CH U*
- *heat, natural gas, at boiler condensating modulating, 15kW/CH U*

9.3 Project organization

In this section, the time plan and the meeting notes are documented.

9.3.1 Time planning

Figure 9 documents the time plan that was followed for this project. The live version can be found here. Access is given upon request.

5	Tasks	Start date	End date	Timeline (gray = past, yellow = active, green = future, red = overdue)	Status
6	Attend disposition colloquium	Nov 26, 2024	Nov 26, 2024		Complete
7	Project meeting #1 - Elke, René	Jan 8, 2025	Jan 8, 2025		Complete
8	Perform inital literature research	Jan 8, 2025	Jan 15, 2025		Complete
9	Check existence of background data in Ecoinvent/KBOB/UVEK	Jan 15, 2025	Jan 29, 2025		Complete
10	Perform screening LCA	Jan 29, 2025	Feb 19, 2025		Complete
11	Create required data questionaire	Feb 17, 2025	Feb 19, 2025		Complete
12	Research online data sources to fill the questionnaire	Jan 29, 2025	Mar 19, 2025		Complete
13	Project meeting #2 - Elke, René	Feb 19, 2025	Feb 19, 2025		Complete
14	Create time plan	Feb 26, 2025	Mar 2, 2025		Complete
15	Document research question and hypothesis	Mar 1, 2025	Mar 8, 2025		Complete
16	Create draft of research agreement based on template	Mar 1, 2025	Mar 8, 2025		Complete
17	Send out draft of research agreement for feedback	Mar 3, 2025	Mar 8, 2025		Complete
18	Create system diagram and functional unit (LCA part 1)	Feb 19, 2025	Mar 14, 2025		Complete
19	Define goal and scope (LCA part 1)	Feb 19, 2025	Mar 14, 2025		Complete
20	Finalize and sign research agreement	Mar 8, 2025	Mar 14, 2025		Complete
21	Create inventory analysis (LCA part 2)	Feb 13, 2025	Mar 30, 2025		Complete
22	Project meeting #3 - Elke, René	Mar 19, 2025	Mar 19, 2025		Complete
23	Perform impact assessment (LCA part 3) and interpretation (LCA part 4)	Mar 24, 2025	May 27, 2025		Complete
24	Send out impact assessment results	Apr 22, 2025	Apr 22, 2025		Complete
25	Project meeting #4 (Discuss results) - Elke, René	Apr 28, 2025	Apr 29, 2025		Complete
26	Perform sensitivity analysis	May 19, 2025	Jun 7, 2025		Active
27	Project meeting #5 (Discuss results) - Elke, René	May 27, 2025	May 28, 2025		Complete
28	Finalize literature study	Jun 8, 2025	Jun 22, 2025		Complete
29	Finalize the paper	Jun 2, 2025	Jun 29, 2025		Upcoming
30	Hand in paper	Jun 29, 2025	Jun 29, 2025		Upcoming
31	Prepare slides for presentation	Jul 1, 2025	Jul 8, 2025		Upcoming
32	Test run presentation	Jul 2, 2025	Jul 8, 2025		Upcoming
33	Attend defence colloquium	Jul 8, 2025	Jul 8, 2025		Upcoming
34	Give presentation	Jul 8, 2025	Jul 8, 2025		Upcoming

Figure 9: Gantt chart used for time planning.

9.3.2 Meeting notes

The notes for the meetings can be found here. Access is given upon request.

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