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

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

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1 Abstract

A Life Cycle Impact Assessment (LCIA) is performed for a solar district heating community project in Bracht, Rauschenberg, Germany.

2 Introduction

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.

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 [3]. According to [4], 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.

STCs are a mature technology. In 2023, the total operational solar thermal capacity reached 560 GWth, which covers roughly 800 km2 of collector area [4]. 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, LCA case studies exist for the district heating system in Milan [5] and Marseille [6]. LCA, in particular the ReCiPe method, has been used to assess the environmental impact of different STC powered district heating configurations by [7]. The outcome was that larger systems that serve many households have a lower environmental impact per energy unit served.

In [8], the authors provide an LCA study of a STC plant connected to the Geneva district heat network and find that there is no LCA data available for the coupling of large scale solar thermal installations and district heating networks, and provides suggested numbers that could be used to complement district heat production routes in the KBOB database.

For the community project in Bracht, while the economic viability of the project in comparison to energetic renovation was analysed by [9], the environmental impact has not yet been studied in detail. This is the subject of the given study.

3 Methodology and research questions

The foreground data is collected from various online sources and combined with background data from the Ecoinvent v3 database [10] and from the UVEK LCI database version DQRv2:2025 database [11]. Environmental impacts are assessed using the mid-point level Environmental Footprint (EF) method [12], and the Ecological Scarcity 2021 v1.04 method [13] at the single score level with UVEK LCI weighting set. The LCIA is performed using the SimaPro 9.6.0.1 software [14].

The research questions are 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 for the production, construction, and use stages in the life cycle? The benefits of the STC based system with a seasonal heat storage component included will be assessed in comparison to the same system without seasonal heat storage under several assumed loss coefficients for the storage component (sensitivity analysis). The hypothesis is that the seasonal storage component will lower the environmental impact.

4 Goal and scope

The goal and scope definition of an LCA provides a description of the product system and its system boundaries, and a functional unit.

The district heating project that is the topic of this analysis is led by a cooperative comprising future household consumers and the local council. The project setup consists of a solar thermal collector field, a seasonal storage unit also called Pit Thermal Energy Storage (PTES), a heat pump which is using power from the grid, a buffer storage unit, a backup biomass combustion unit that if required can be used as an alternative source of heat (for the cases where there is no availability of heat from neither the solar collector nor the storage), and a distribution network for the customer households (see Figure 1). A receiver unit is installed in each participating household. There are at least 180 consumer households expected, which is roughly 60% of all households in the community.

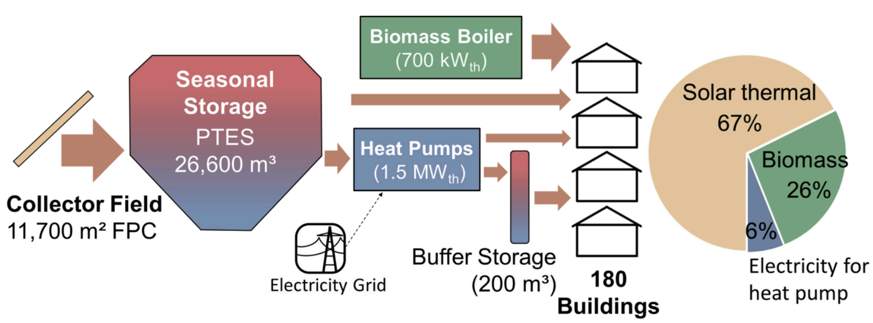


Figure 1: System overview for the Bracht community district heating network. (Source: University of Kassel)

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

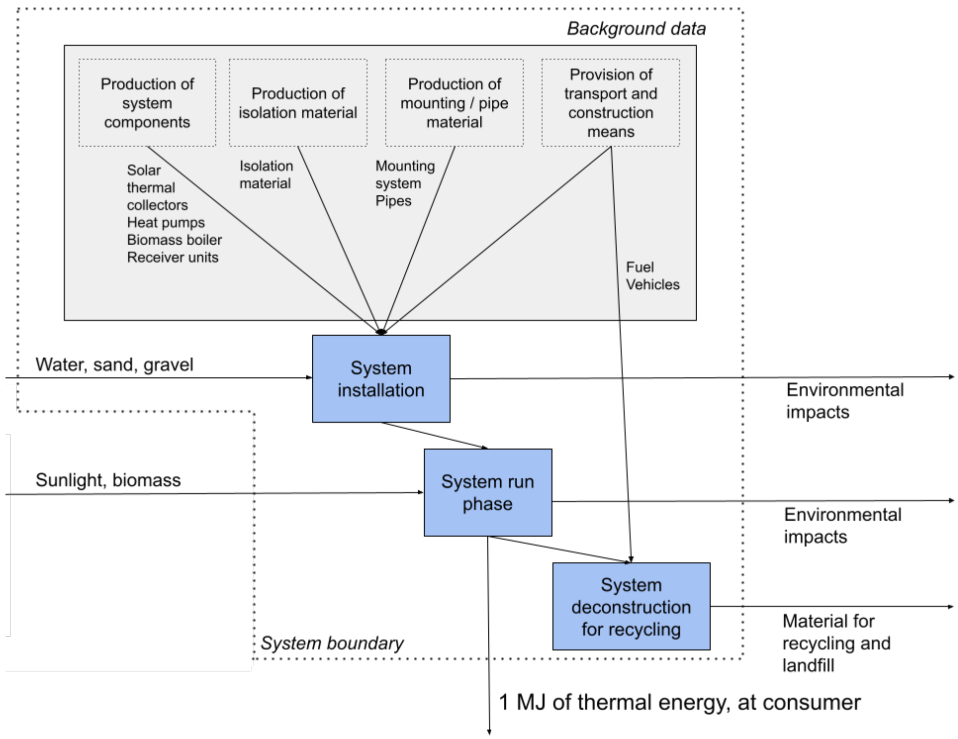


Figure 2: System diagram for the Bracht community district heating network, with functional unit as stated.

System deconstruction was modeled for the solar thermal collector field and the seasonal storage unit. Disposal (via municipal waste incineration) of the plastic material used for seasonal storage unit sealing and insulation was included in the modelling.

5 Life Cycle Inventory

There is a lot of information available on the project website [15], which has been used as the source for detailed life cycle inventory information for solar thermal collector field, seasonal storage unit, and heat preparation (heat pump, buffer storage, installation facility, and consumer installations) can be found in the supporting information appendix in Section 9.1. The heat transport network was modeled based on existing UVEK LCI data. The modelling default electricity source was chosen to be the European Network of Transmission System Operators for Electricity (ENTSO-E) production mix [11], aiming to make the model representative for a plant located in the European region.

The remainder of this section describes the assumptions for component lifetimes, electricity requirements and 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 [16].

Table 1

Component	Years	Multiplier	Source
Solar thermal collector	30	1.67	[17]
Seasonal storage unit	30	1.67	[16]
Heat pump	20	2.5	[18]
Heat buffer storage	20	2.5	[17]
Heat installation facility	50	1	[19]
Heat exchange station at consumer	20	2.5	[16]
Heat transport network	50	1	[16]

5.2 Electrical power requirements and loss coefficient assumptions

Several estimations of annual collector output can be found in the relevant performance data from [20] for the solar thermal collectors used in this project. They are based on geographical location and on the desired output temperature. The geographically closest matching entry is 5.283 kWh per collector per year for the Würzburg location and 75 degrees output. For the given 855 collectors, this leads to an estimate of 4.517 MWh per year.

The Bracht documentation [21] states that in total, 2.700 MWh per year are expected to reach consumer households. This means that the assumed loss coefficients for the storage unit and in the pipes together is estimated to amount to a significant factor of 40% loss.

The electrical power is generated to 67% from the solar thermal collectors and stored (2.258 MWh), to 26% from biomass (904 MWh), and to 6% from the grid (209 MWh). This is the percentage distribution included in Figure 1.

There is no detailed information how the expected loss was estimated. However, based on the published numbers and an assumed 20% loss coefficient in the pipes, the resulting expected loss in the seasonal storage unit can be calculated at 50%. These assumptions were used in the modelling. Further discussion of loss coefficients and a related sensitivity analysis can be found in Section 7.3.

6 Results

For answering the first research question about the relative environmental impact of the additional electricity and the supplemental biomass boiler, the influence of the different components of the solar thermal district heating system on environmental impact was assessed using the Ecological Scarcity 2021 v1.04 method at the single score level with UVEK LCI weighting set.

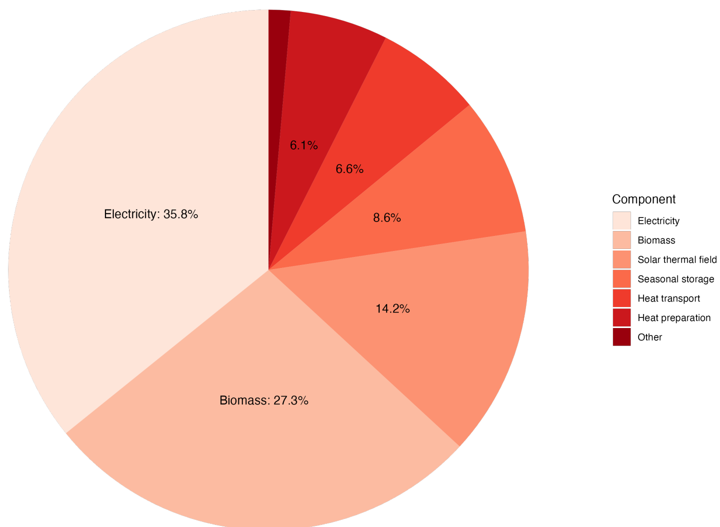


Figure 3: Relative environmental impact of Bracht community district heating network system components using the Ecological Scarcity 2021 v1.04 method at the single score level, using the UVEK LCI weighting set.

The results are shown in Figure 3. While the solar thermal collectors contribute two thirds of the energy production (see Figure 1), their relative environmental impact amounts to less than 15%. The biomass and electricity (ENTSO-E as discussed in Section 5) required in the setup for one third of the energy production contribute two thirds of the environmental impact. This is the combined environmental impact based on the UVEK LCI weighting for the relative importance of the damage categories.

For further detail on the damage categories involved, Figure 4 provides the individual results for the most relevant damage categories *Climate change*, *Particulate matter*, *Eutrophication, marine*, *Land use*, *Resource use, minerals and metals* and *Resource use, fossils*. It reveals that the biomass required in the setup is the dominant influence in the damage categories land use, particulate matter (PM), and marine eutrophication. Electricity dominates the impact for fossil resource use and climate change. The resource use is most heavily influenced by heat preparation and the solar thermal collectors. The seasonal storage unit impacts climate change and fossil resource use.

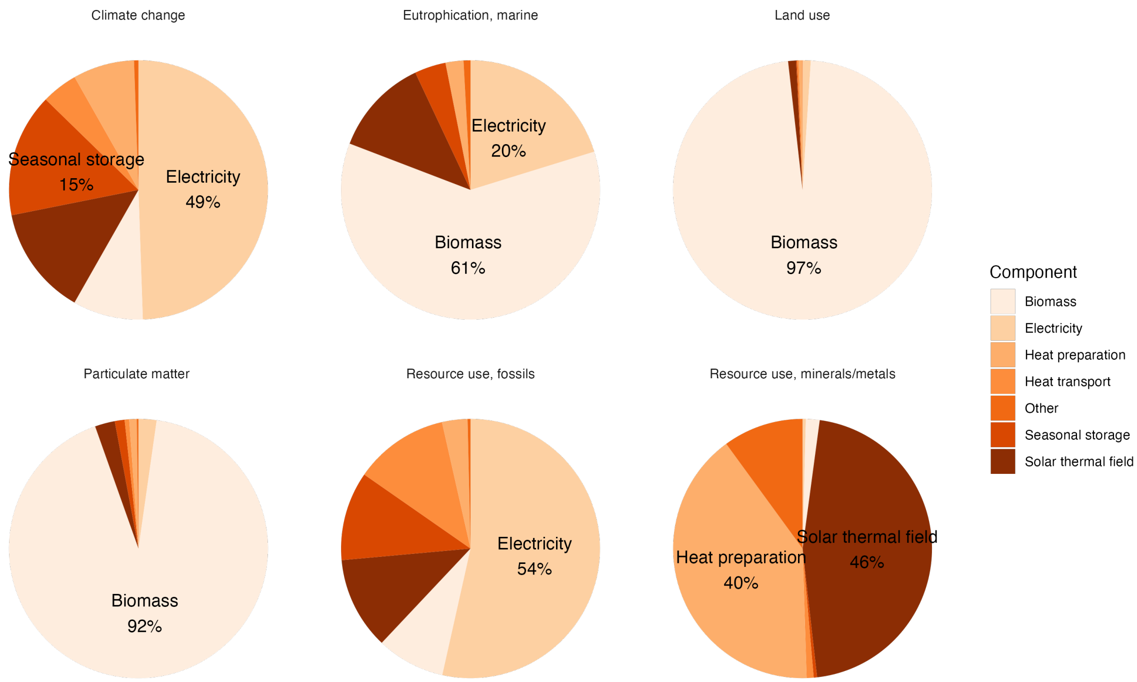


Figure 4: Relative environmental impact of Bracht community district heating network system components using the Environmental Footprint Method

To summarize, the electricity and biomass required to power and supplement the system play the dominant roles with respect to the overall environmental impact.

The electricity use can not be avoided since it is required to run the heat pump. Its impact can be lowered by using green energy, which will be investigated in the following comparisons. The opportunities and effects of using less biomass by lowering heat loss coefficients are assessed in Section 7.3.

Figure 5 and Figure 6 show the results for comparing the environmental impacts of solar thermal based district network heat to other forms of district heating (DH) available in small communities such as wood chips (biomass), geothermal heat pump, and to the usually available consumer side heating installations (CI) such as a oil or gas boiler.

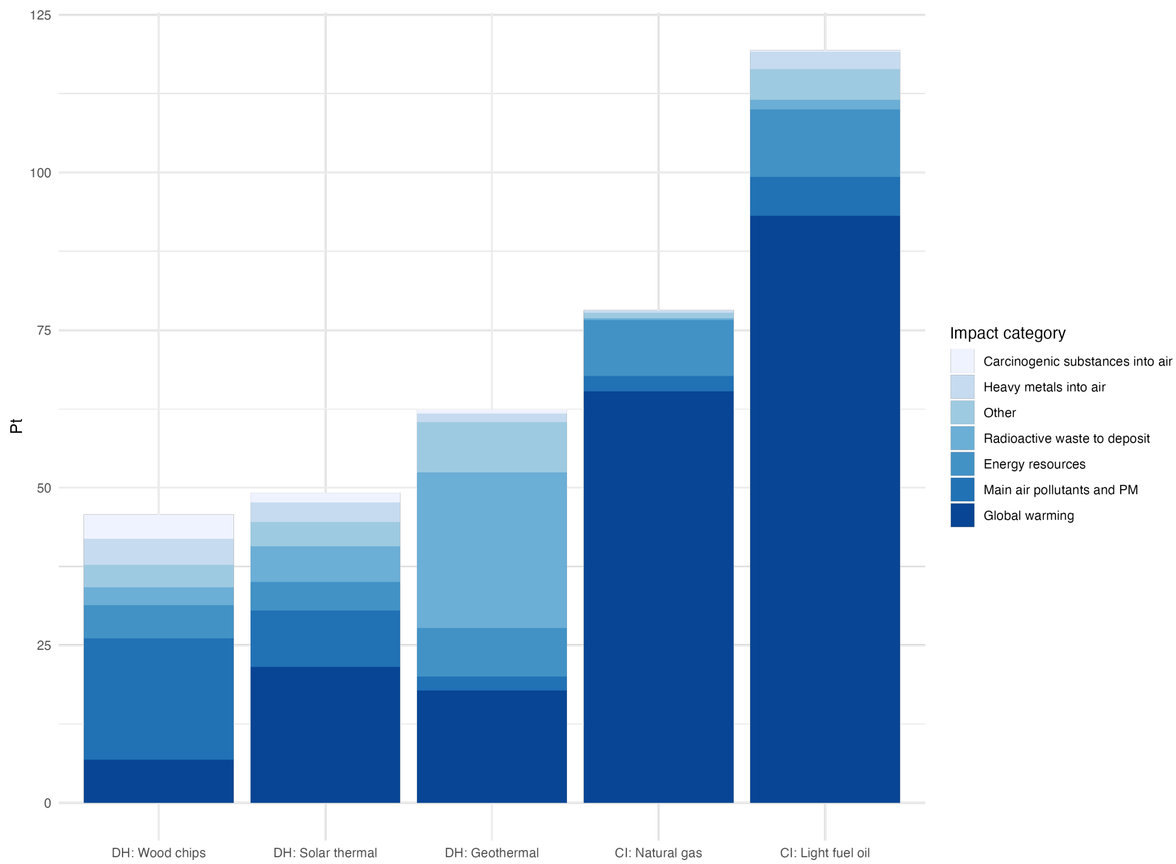


Figure 5: Comparison of environmental impact of Bracht community district heating network to other energy sources for district heating (wood chips, heatpump), and to other types consumer installations (gas, oil). Analysis based on the Ecological Scarcity 2021 v1.04 method at the single score level, with UVEK LCI weighting set.

7 Discussion

As shown in Figure 5, the Bracht setup compares positively to other heating technologies in terms of environmental impact. Based on the analysis using the Ecological Scarcity 2021 v1.04 method with UVEK LCI weighting set, it shows a lower environmental impact compared to other relevant district heating setups and to fossil energy based consumer installations. The results visualize that the Bracht system fares better in the “Main air pollutants and Particulate Matter (PM)” category in comparison to a completely wood chips based energy source for

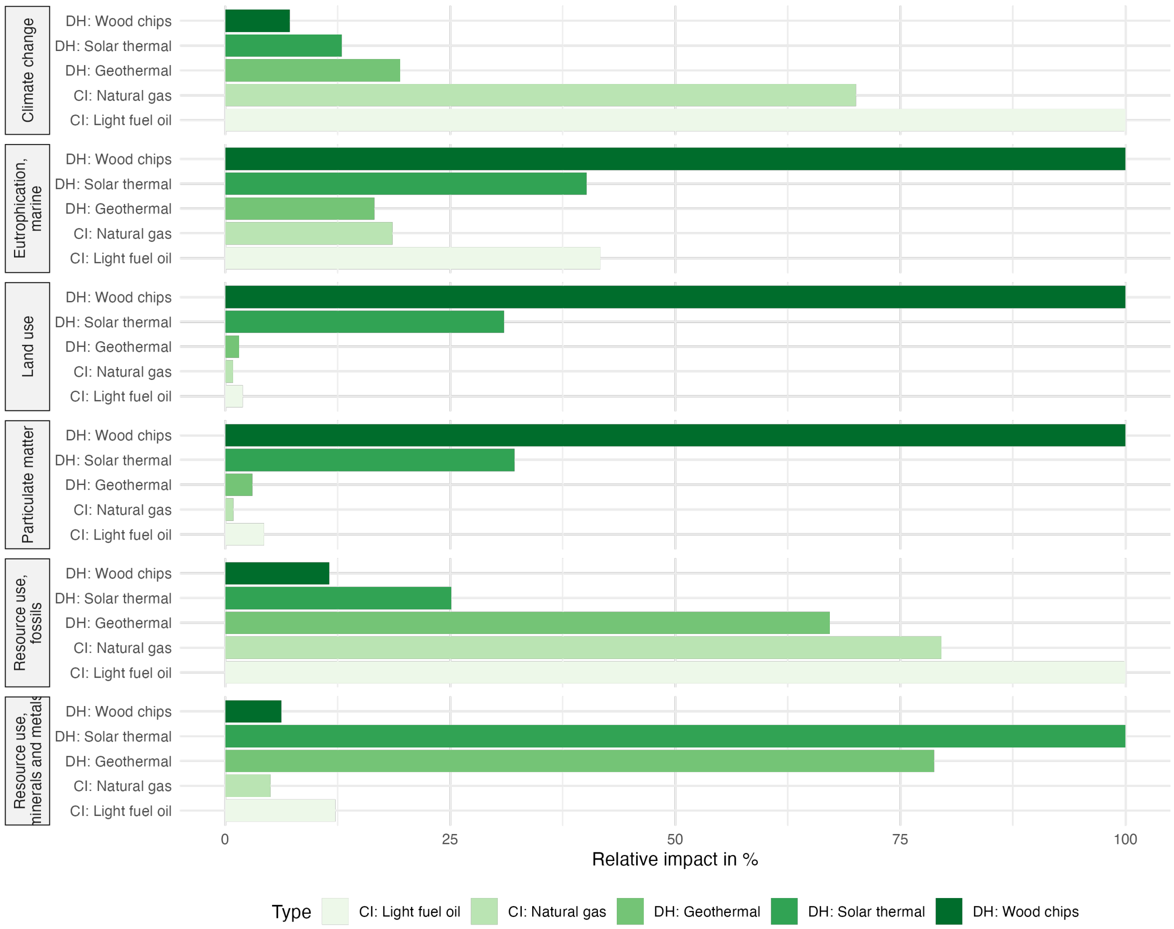


Figure 6: Damage assessment using the Environmental Footprint Method, visualized as relative environmental impacts in comparison.

district heating, while the impact from the biomass energy used in the Bracht system is still visible in the results. The geothermal based district heating would perform better if there wasn't as much radioactive waste to deposit. The gas and oil based customer installations compare the least well in the selection because of the high impacts in the global warming category.

Related results are shown in Figure 6 when looking at the Environmental Footprint Method. Again the wood chips based energy source for district heating fares worst in the particulate matter category. It is also returning the worst results for land use, euthrophication (marine and terrestrial), human toxicity (cancer), and photochemical ozone formation. The oil burner returns the worst results for acidification, climate change, freshwater ecotoxicity, human toxicity (non-cancer), and fossil resource use. The gas burner shows bad results for climate change and ozone depletion. The geothermal heat pump district heating is performing badly for euthrophication (freshwater) and for ionising radiation. The solar thermal based district heating returns the worst results for resource use (minerals and metals).

7.1 Modeling limitations

- Winter electricity
- Heatpump 24x
- Transport network lifetime 30 years / 50 years

7.2 Sensitivity analysis: Source of electricity

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.

As summarized in [22], the relevant parameters affecting heat loss in the pipes are the length of the network which depends on the transmission distance relative to demand, the system age, and the operating temperature. The cited loss coefficient numbers for pipe loss range between 5% and 35%. The Bracht setup has a long transmission distance of 8800 meters because of the rural setup, and a planned operating temperature of 85 degrees Celsius. Both of these factors affect performance negatively. Therefore, even if the system is brand new and therefore modern, assuming a 20% heat loss is realistic. The open source modelling tool Energy Transition Model [23] suggests 15% as a sensible default for modelling heat loss in the pipes of modern district heating networks based on real world numbers. Note that in the comparison in Figure 5, the data for the other energy sources for district heating (wood chips, heatpump) used a 5% to 10% assumption which means that the solar thermal data with the 20% assumption is disadvantaged in the comparison.

If the heat loss in the Bracht pipes could be lowered to 10% by using a lower operating temperature, that would result in efficiency savings of 335 MWh per year which would in turn not require production from the biomass boiler. This is significant since it amounts to roughly one third of the energy coming from biomass. Figure 7 shows that this results in a reduction from 39 to 34 Ecopoints per MJ of district heat, which amounts to a 12% reduction. The main impact factor changed is in the "Main air pollutants and Particulate Matter (PM)" category.

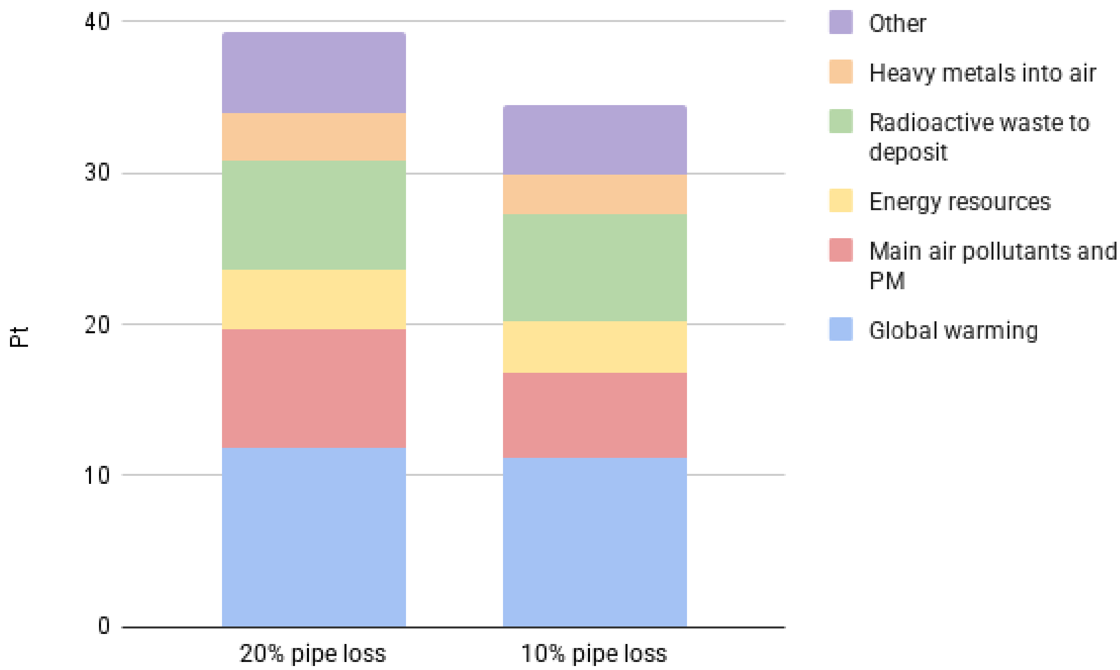


Figure 7: Potential savings when halfing heat loss in pipes.

In [24], the authors report a 26% loss of heat production in the storage unit amounted to of heat production. The Energy Transition Model [23] suggests 30% as a sensible default for modelling heat loss in the storage unit. This study [25] 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. The assumption for Bracht, which is 50% loss, seems to be on the conservative side. If it can be lowered to 30%, which seems feasible given the scientific results cited, that would cancel out the entirety of energy from biomass required. This would reduce the environmental impact from 39 to 26 Ecopoints per MJ of district heat, which is a reduction of 33%, as shown in Figure 8.

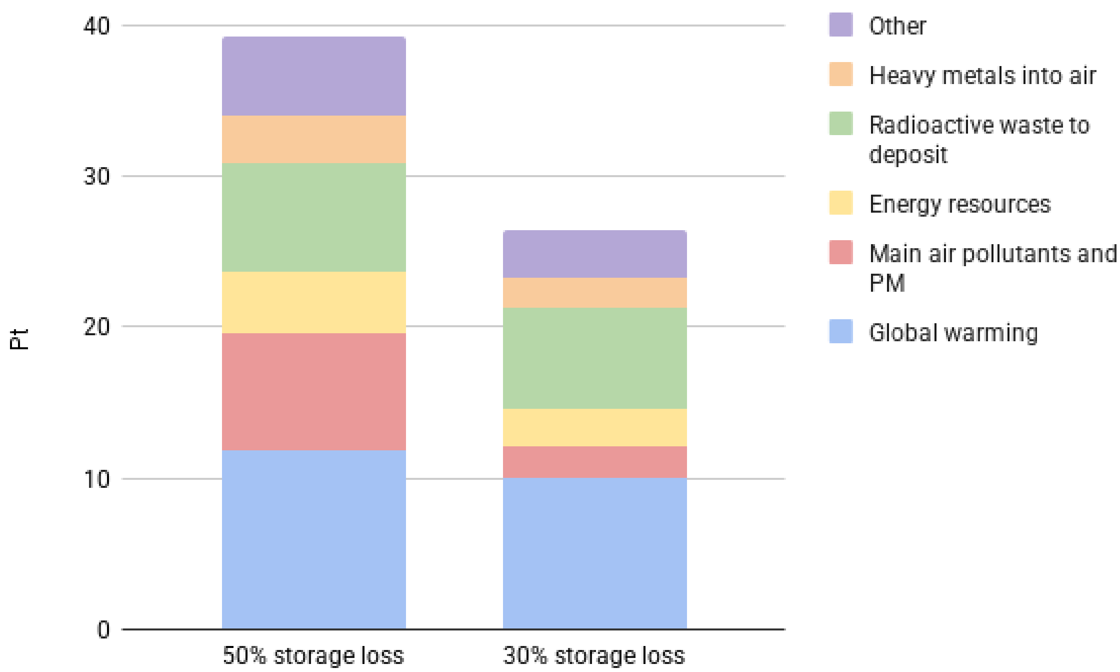


Figure 8: Potential savings when lowering heat loss in storage from 50% to 30%.

8 Conclusion

A case study life cycle assessment was performed for the solar district heating community project in Bracht, Rauschenberg, Germany. The results compare favorably to other heating technologies in terms of environmental impact. To further improve, the recommendations are (1) to consider a lower operating temperature for the system to achieve better overall efficiency through avoided heat losses, (2) to use green energy for running the heat pump, and (3) to lower or event completely remove the amount of biomass burnt by improving the heat loss coefficients for storage unit and transmission pipes.

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)	[26]
Type	Flat-plate collectors Vitosol 100-F XF13 Viessmann	[26] [27] [20]
Land use	23.500 m^2	[26]
Mounting infrastructure material	15 t steel	[15]
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

Dimension	Value	Source

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 9.

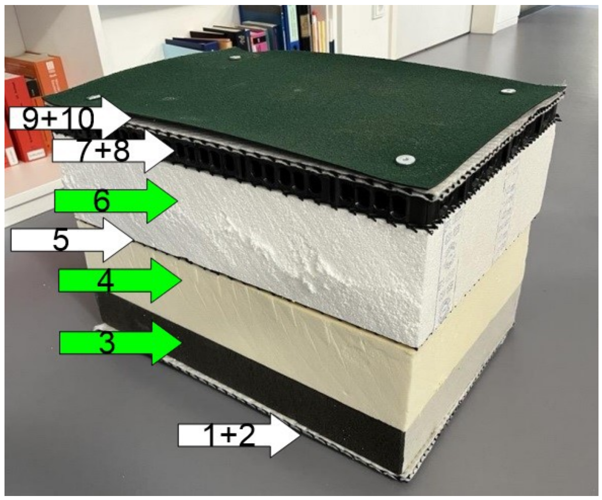


Figure 9: Floating cover profile. Source: Bracht community.

Table 3

Dimension	Value	Source
Volume	26'600 m^3	Figure 1
Resource: water	26'600 m^3 filled from local source	[28]
Cover layer 1, 10	Polyethylen (HDPE) sealing membranes 1.5 mm, 1.5 kg / m^2	[28], estimated weight
Cover layer 2, 9	Fleece (0.1 kg / m^2) laminated plastic grid (HDPE, 0.5 kg / m^2)	[28], estimated weight
Cover layer 3	Foam glass, 8.33 kg / m^2	[28]
Cover layer 4	Polyurethane (bauder foam): 3.125 kg / $m2$	[28]
Cover layer 5, 7, 8	Airing gap made of plastic grid, 0.5 kg / m^2 each	[28], estimated weight
Cover layer 6	Polystyrene (XPS), 3 kg / m^2	[28]
Floating cover dimensions	70 m x 70 m = 4900 m^2	[29]

Dimension	Value	Source
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	[28], estimated weight
Ground liner dimensions	Bottom 20 m x 20 m, vertical height 15 m, surface area on each of the four sides 5250 m^2	[29]
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)	[26] [30]
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	[26]
Controller	Vitocontrol 200-M	[26] [31]
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 itself is shown in Figure 10.

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

9.3 Project organization

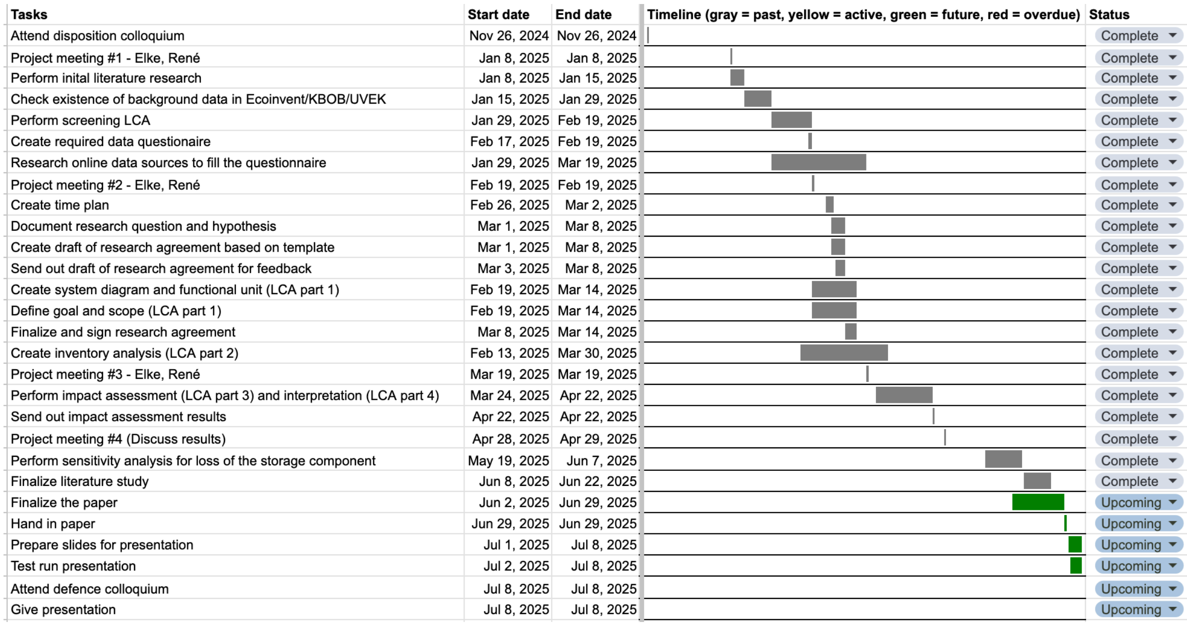
In this section, the time plan and the meeting notes are documented.

1	Products			
2	district heat, at consumer, solar thermal, 1MW/MJ/RER U	1	MJ	
3				
4	Resources			
5	Water, cooling, unspecified natural origin, DE	SSU_volume_m3/STC_prod_MJ_lifetime	m3	SSU
6	Land use II-III	Plant_size_m2*Lifetime/STC_prod_MJ_lifetime	m2a	Total plant
7				
8	Materials/fuels			
9	steel, electric, unalloyed, at plant/CH U	Steel_kg/STC_prod_MJ_lifetime	kg	STC
10	flat plate collector for PVT, aluminium copper absorber, at plant/CH/I U	(STC_size_m2*Mult30To50)/STC_prod_MJ_lifetime	m2	STC
11	transport, transoceanic freight ship/tkm/OCE U	(STC_weight_t_total * Freight_ship_dist_km)/STC_prod_MJ_lifetime	tkm	STC
12	transport, freight, lorry 40-50 metric ton, EURO 5/RER U	(STC_weight_t_total * Lorry_dist_km)/STC_prod_MJ_lifetime	tkm	STC
13	Polyethylene, HDPE, granulate, at plant/RER U	(SSU_top_m2*1.5*2*Mult30To50)/STC_prod_MJ_lifetime	kg	SSU layer 1, 10: Sealing membrane
14	Polyethylene, HDPE, granulate, at plant/RER U	(SSU_top_m2*0.5*2*Mult30To50)/STC_prod_MJ_lifetime	kg	SSU layer 2, 9: Plastic grid
15	Fleece, polyethylene, at plant/RER U	(SSU_top_m2*0.1*2*Mult30To50)/STC_prod_MJ_lifetime	kg	SSU layer 2, 9: Fleece
16	Foam glass, at plant/RER U	(SSU_top_m2*8.33*Mult30To50)/STC_prod_MJ_lifetime	kg	SSU layer 3: Glapor
17	Polyurethane, rigid foam, at plant/RER U	(SSU_top_m2*3.125*Mult30To50)/STC_prod_MJ_lifetime	kg	SSU layer 4: Bauder Foam
18	Polyethylene, HDPE, granulate, at plant/RER U	(SSU_top_m2*0.5*3*Mult30To50)/STC_prod_MJ_lifetime	kg	SSU layer 5, 7, 8: Plastic grid
19	Polystyrene, extruded (XPS), at plant/RER U	(SSU_top_m2*3*Mult30To50)/STC_prod_MJ_lifetime	kg	SSU layer 6: XPS
20	Polyethylene, HDPE, granulate, at plant/RER U	((SSU_ground_m2)*2.5*Mult30To50)/STC_prod_MJ_lifetime	kg	SSU ground liner
21	transport, transoceanic freight ship/tkm/OCE U	((((SSU_top_m2*20.155) +(SSU_ground_m2*2.5))*Mult30To50)/1000 * Freight_ship_dist_km)/STC_prod_MJ_lifetime	tkm	SSU transport
22	transport, freight, lorry 40-50 metric ton, EURO 5/RER U	((((SSU_top_m2*20.155) + (SSU_ground_m2*2.5))*Mult30To50)/1000 * Lorry_dist_km)/STC_prod_MJ_lifetime	tkm	SSU transport
23	excavation, hydraulic digger, average/m3/CH U	26600/STC_prod_MJ_lifetime	m3	SSU excavation
24	heat pump, brine-water, 50kW/RER/I U	(25*Mult20To50)/STC_prod_MJ_lifetime	p	HP heat pump
25	Heat storage 2000l, at plant/CH/I U	(100*Mult20To50)/STC_prod_MJ_lifetime	p	HP heat pump
26	Building, hall/CH/I U	50/STC_prod_MJ_lifetime	m2	HP building
27	Heat exchanger of Mini CHP plant/CH/I U	(180*Mult20To50)/STC_prod_MJ_lifetime	p	Distribution infrastructure
28	transport, district heat, large area network, for warm water/MJ/CH/I U	(STC_prod_MWh_per_a*Lifetime)/STC_prod_MJ_lifetime	MWh	Lifetime 30 years
29				
30	Electricity/heat			
31	electricity, production mix ENTSO/kWh/ENTSO U	(209*Lifetime)/STC_prod_MJ_lifetime	MWh	
32	heat, mixed chips from forest, at furnace 1000kW/MJ/CH U	(904*Lifetime)/STC_prod_MJ_lifetime	MWh	
33				
34	Waste to treatment			
35	deconstruction, average/CH U	(STC_weight_t_total*1000 + (((SSU_top_m2*20.155) +(SSU_bottom_m2*2.5))*Mult30To50))/STC_prod_MJ_lifetime	kg	
36	disposal, polyethylene, 0.4% water, to municipal incineration/kg/CH U	((SSU_top_m2*5.5 +SSU_ground_m2*2.5)*Mult30To50) / STC_prod_MJ_lifetime	kg	
37	disposal, polyurethane, 0.2% water, to municipal incineration/kg/CH U	((SSU_top_m2*3.125)*Mult30To50) / STC_prod_MJ_lifetime	kg	
38	disposal, polystyrene, 0.2% water, to municipal incineration/kg/CH U	((SSU_top_m2*3)*Mult30To50) / STC_prod_MJ_lifetime	kg	

Figure 10: SimaPro data excerpt.

9.3.1 Time planning

Figure 11 documents the time plan that was followed for this project. The live version can be found here. Access is given upon request.



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

Figure 11: 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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