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Use of Waste Heat Potential and Flexibility Elements to Speed up Decarbonisation in Austrian Thermal Spas

A Potential Study

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Abstract. Austria's 38 thermal baths offers a unique opportunity to harness deep hydrothermal geothermal energy, reducing their reliance on fossil fuels and decreasing CO2 emissions by over 50,000 tonnes annually. The GEOMAT project's core focus is on efficiency enhancement by integrating various heat pump technologies, optimizing energy management, and transitioning to renewable energy sources for complete decarbonization. Geothermal energy is pivotal for Austria's sustainable energy future, with a particular emphasis on making it economically appealing for significant energy consumers, including thermal spas, municipalities, energy providers, and industries. By leveraging innovative heat pump systems and intelligent control concepts, GEOMAT aims to maximize energy efficiency and create flexibility in electricity and heating networks, thereby fostering synergy and systemic benefits.

Keywords: Geothermal Heat, Thermal Spas, Heat Pump, District Heating, Energy Management, Flexibility

1 Introduction

Austria, renowned for its 38 thermal baths, is a top European tourist destination with immense potential for harnessing deep hydrothermal geothermal energy from depths exceeding 400 meters within water-bearing strata [1]. These thermal baths are significant energy consumers, with the potential to cut carbon emissions by up to 50,000 tons of CO2 annually. To preserve these facilities and make them more environmentally friendly, the focus should be on increasing the use of geothermal heat for their energy needs [2]. This involves optimizing existing infrastructure and exploring innovative solutions. Many thermal spas in Austria currently rely on fossil fuels for their substantial energy demands. For example, Sonnentherme Lutzmannsburg consumes 16 GWh of heat from natural gas each year, while Reduce Therme Bad Tatzmannsdorf relies on 9 GWh of heat from natural gas, and H2O Hoteltherme utilizes 5 GWh of heat sourced from biomass. Therefore, these thermal bath facilities hold substantial potential to play a crucial role in decarbonization and energy efficiency efforts by 2030/2050.

2 Scope and Methodology

Thermal bath facilities in Austria are unique energy systems with distinct characteristics, including [3, 4, 5, 6, 7]:

- Untapped waste heat potential from sources like splashing water.
- Opportunities for energy savings through reduced pool heat losses.
- Potential for energy savings through temperature-optimized supply systems, including infrastructure upgrades like heat exchangers.
- Large storage capacity in pool water content, often overlooked in control strategies.
- Complex control challenges due to simultaneous heating and cooling demands, often managed using simplistic methods.
- Utilization of thermal capacities for peak shaving and load shifting, tied to visitor patterns and weather forecasts, but often lacking advanced data-driven forecasting.
- Potential for effective energy management systems to integrate supply and demand-side factors.

The current GEO.MAT project aims to create carbon-neutral thermal baths by optimizing geothermal energy utilization. This includes repurposing unused splashing water at 30°C, reducing pool heat losses, and implementing temperature-oriented heating supply. The project also explores integrating non-stationary splashing water utilization and other renewable resources like biomass and solar power. In addition to harnessing the energetic potential of splash water waste to save energy by reducing pool losses, leveraging thermal capacities through peak shaving and load shifting, considering external control inputs such as visitor profiles, weather forecasts, and temperature-oriented heating supply, as well as further integrating renewables like biomass or solar energy, the development of an appropriate Energy Management System (EMS) is vital for such a complex system.

The shift to a carbon-neutral energy supply therefore involves several measures:

- Using geothermal splashing water (waste heat at 30°C) through AHP and/or CHP to reduce the external heat demand (gas or biomass)
- Implementing demand-side management with data predictive control (DPC) for peak shaving and load shifting.
- Applying model predictive control (MPC) for the supply side, considering generated forecasts.
- Integrating all measures for optimal operation and load, including sector coupling options based on the facilities' high thermal inertia.
- Replacing gas with biomass and incorporating flue gas condensation through AHP

3 Results Demonstration Cases

First results of potential study and development of energy system concepts including different measures for utilizing geothermal waste heat and increasing renewables' integration in thermal baths will be summarized for the two Austrian demonstration sites. The two demonstration sites are briefly described below.

Demo project 1: Sonnentherme Lutzmannsburg – Boundary conditions

Sonnentherme Lutzmannsburg, located in east Austria, consumes currently about 1.67 million m³ natural gas for its operation. The carbon emissions are over 4,200 per year for heating. Operational details of Sonnentherme include the utilization of a geothermal borehole with a maximum flow rate of 18 m³/h, operating at 32 °C. Additionally, the facility deploys five gas boilers with a combined capacity of around 5.5 MW_{th}. Integration of a Compression Heat Pump (CHP) meets refrigeration demand, capable of delivering up to 114 kW (7/12°C). The presence of a pool water volume totaling approximately 2,200 m³, with an average flow reaching up to 7.3 m³/h, should be analysed as a flexibility element. Wastewater generated from pool operation averages 1,230 m³ per week (with an average flow of up to 10 m³/h), operating at around

30 °C. Furthermore, waste heat from the chiller at the Hotel Sonnenpark should be analysed for providing up to 790 kW of additional energy.

Demo project 2: H2O Hoteltherme – Boundary conditions

The H2O Hotel-Therme in Bad Waltersdorf, situated in the southeast of Austria, operates a geothermal well (depth: 498 m, production: 9 m³/h at 32°C) and is connected to a local district heating network. The annual heat demand is 6.4 GWh, and the electricity demand is 3.4 GWh. There's considerable potential to recover waste heat from thermal wastewater, climate cooling supply, and drinking water cooling. Establishing bidirectional use with the district heating network (for both heat and cold) aims to conserve biomass resources and enhance the heating plant's efficiency during summer and transitional operation.

In both demonstrations, the focus is on efficiently utilizing geothermal waste heat, optimizing control systems, and reducing carbon emissions, contributing to more sustainable and environmentally friendly thermal bath operations in Austria. In the next part, the results of the potential survey (exemplary of demo 1) and the concept development (exemplary of demo 2) are presented as examples.

3.1 Potential CO_2 Reduction

To assess the potential for CO_2 reduction (example of demo 1), an initial step involved analyzing the load profile of the entire gas consumption, provided by the grid operator on an hourly basis. However, further thermal energy flows were not recorded. Through consumption estimations, it was determined that the "Sportbecken" and "Rutschen-Pufferbecken" are significant consumers. Consequently, a measurement campaign was conducted to examine these areas. Figure 1 illustrates the load profile for a typical day in April.

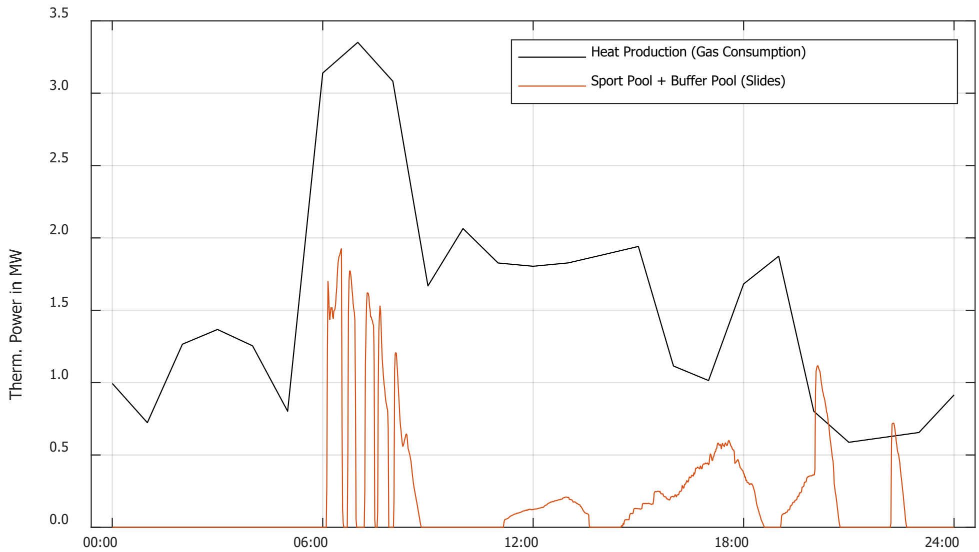

Figure 1. *Comparison of heat production (gas consumption) and two of the largest heat consumers based on an exemplary daily pattern.*

The comparison of the load curves indicates peak loads in the morning due to heating up processes. Implementing peak shaving through intelligent control strategies presents an opportunity for optimizing the heat exchanger and distribution network. Additionally, replacing the current gas boiler with a biomass heating plant in the future could benefit from load balancing.

The importance of the two selected pools is evident in Figure 2, which displays a continuous line representing a week in April and highlights their share of total consumption. Pronounced peak loads are observed, with approximately 85% of the time seeing generation capacity below 50% of the maximum capacity of approximately 4.6 MW.

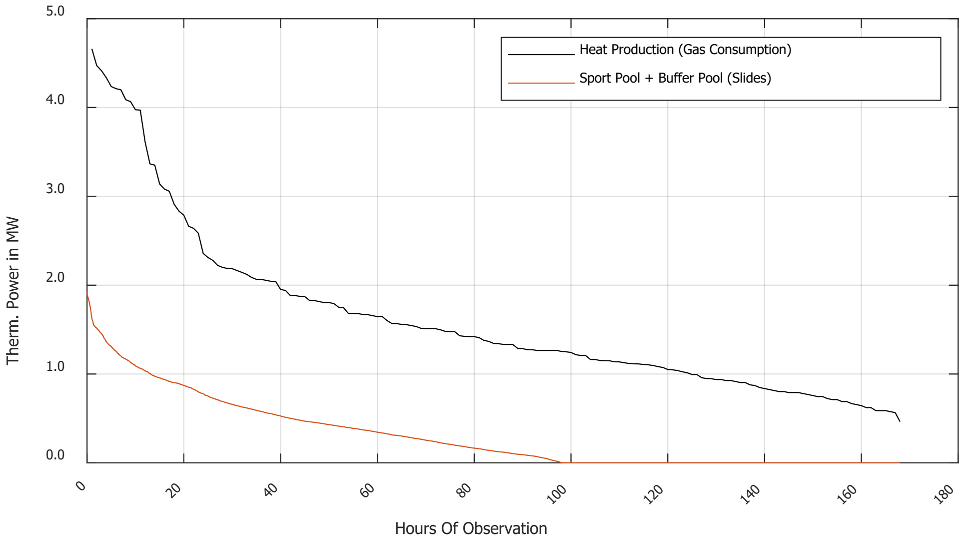

Figure 2. *Comparison of heat production (gas consumption) and two of the largest heat consumers based on the duration curves of an exemplary week.*

Considering this analysis, ongoing project optimization measures focusing on peak shaving, waste water utilization, heat recovery (HR), efficiency measures, and intelligent energy management system are necessary for an optimized energy supply system for thermal baths.

3.2 Potential of waste heat utilization

Investigations are underway regarding the utilization of three splash water basins and two chillers as an untapped energy source. Thermal bath cleaning processes generate wastewater, known as splash water, daily. Due to operational requirements, this water must be stored for a certain duration before disposal into the sewer. Measurements have indicated temperatures exceeding 30°C in this wastewater. Through the utilization of a compression heat pump, the basin volume can be effectively cooled down to 5°C. The energy potential derived from this process surpasses 2 MWh per day and can be harnessed within a 15-hour timeframe. Figure 3 illustrates a potential analysis conducted on a day in March, utilizing splash pool 1 as the heat source and the sports pool as the sink for the heat pump. With the implementation of an appropriate control strategy, the available waste heat can cover 47.6% of the 4.1 MWh required.

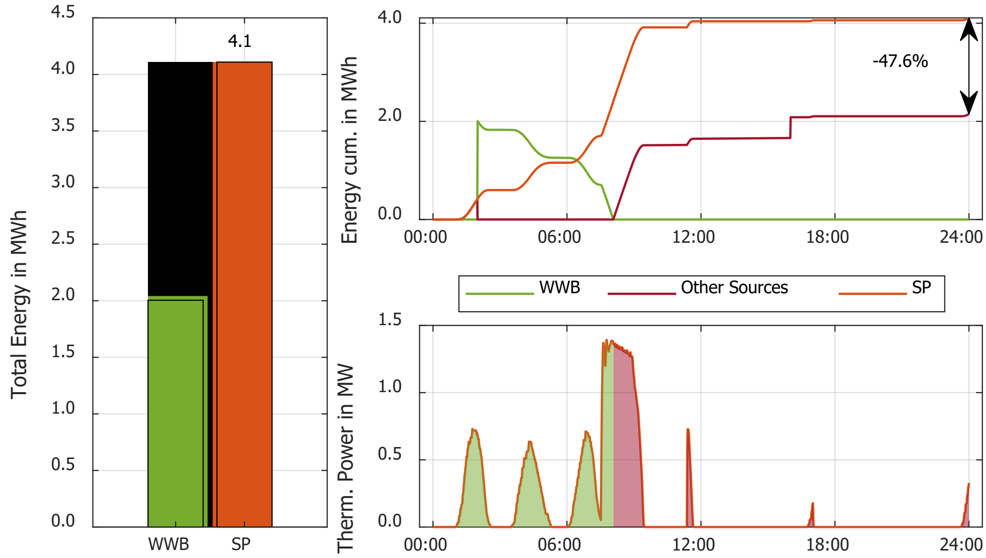

Figure 3. *Comparison of the waste heat utilization potential (backwash basin WWB) with the heating requirement of an outdoor sports pool (SP)*

Chillers present an additional option for harnessing waste heat. The chiller in question serves to meet the cooling demand of the hotel, supplying fan coil units in individual hotel rooms, among other functions. Currently, waste heat from the chiller's condenser is dissipated into the environment via a recooler. To alleviate heat generation, this waste heat can be repurposed to partially fulfill the heating requirements of a pool. However, considerations must be made regarding the usable energy amount, load profiles of the heat source and sink, and temperature levels. In comparison to the previous example involving the utilization of residual heat from backwash water, incorporating the chiller in conjunction with the hotel pool presents less favorable timing conditions. The profiles of energy production and consumption exhibit significant temporal discrepancies, allowing for only 0.7 MWh to be effectively utilized. Thus, there's a need to introduce flexibility into the concept. Ultimately, a substantial portion of the remaining 2.6 MWh is intended to be recovered using intelligent controllers, resulting in significant reductions in electrical energy consumption required for recooler operation.

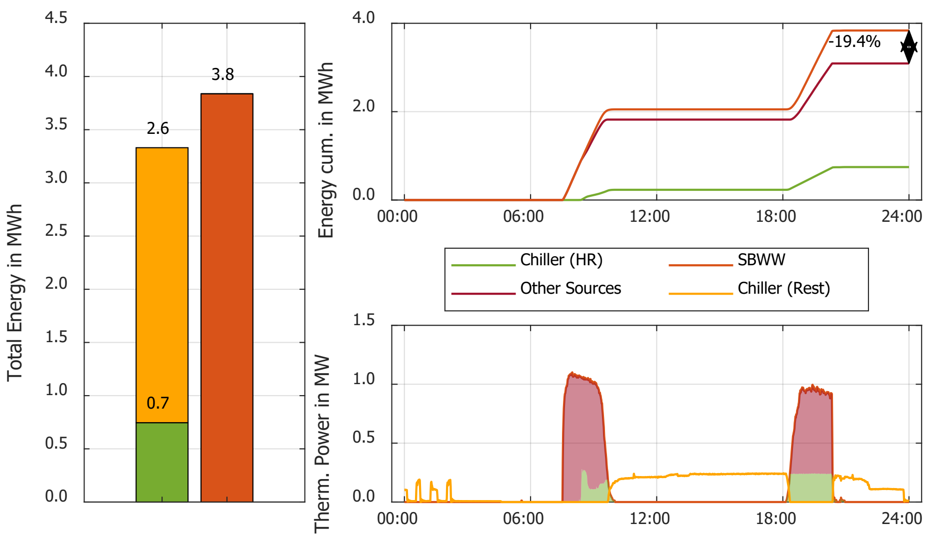

Figure 4. *Comparison of the waste heat utilization potential (chiller (HR)) with the heating requirements of a hotel pool (SBWW)*

The potential study phase revealed considerable energy and CO_2 savings of more than 1,200 tons of CO_2/a and demos site. To make optimum use of this, adjustments to the consumer characteristics are necessary. Load management with an intelligent, predictive controller is necessary for an optimised energy supply system for thermal baths.

3.3 Results concept development

Based on the potential study innovation is illustrated by numerous optimisations in the combined thermal spa and district heating system through efficiency measures, waste heat utilisation, flexibility utilisation and consumption reductions as well as optimised and intelligent control via Model Predictive Control (MPC) for the supply side and optimised data-driven control for the demand side. The main innovation measures are shown for the thermal spa (H2O Hoteltherme) and the connecting heating plant (BIOS) in Figure 5:

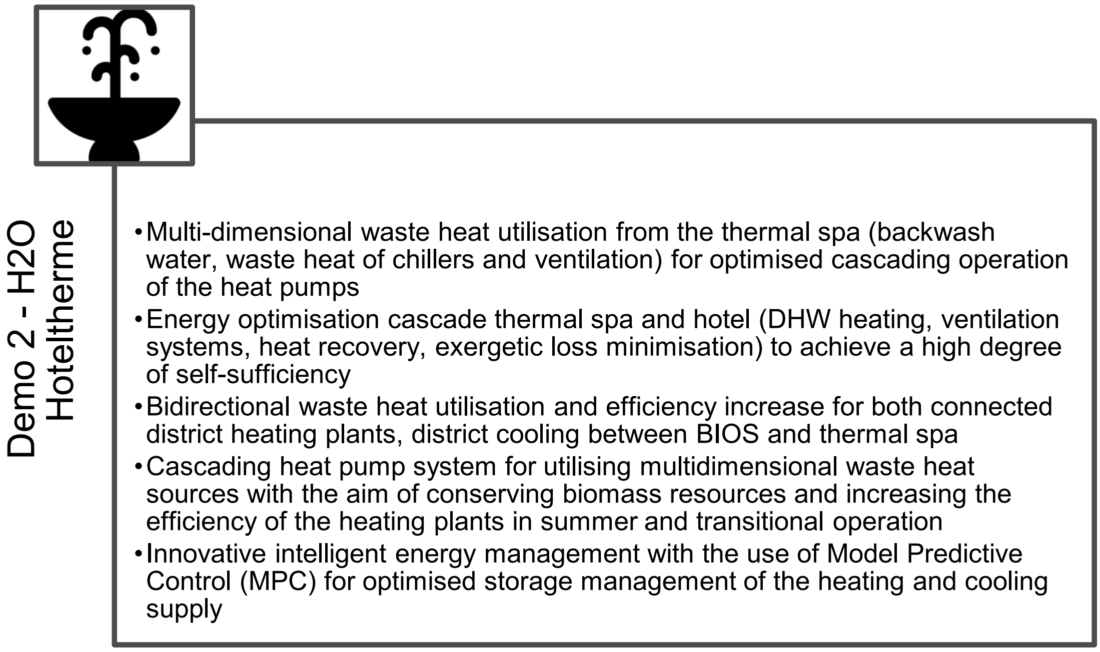

Figure 5: *Overview of all the innovation measures that were identified based on the potential study and are to be mapped in an overall energy system.*

Figure 6 offers a schematic overview of the interconnected elements in the innovation concept. Currently, local heating is provided by a biomass heating plant (BIOS). The geothermal heat source, with temperatures of 32°C, is introduced into the pools and heated to 34°C to 36°C. After filtration, the backwash water is directed to a retention basin. Following a certain residence time to meet hygiene standards, it's cooled and discharged into the sewer at a temperature of 30°C, meeting regulatory requirements. This heat source is available for utilization via a heat pump. Optimization measures in the thermal baths and the connected hotel can harness waste heat from climate cold water (ventilation systems) to operate the heat pump. Optimization and efficiency measures in hot water preparation, ventilation systems with innovative heat recovery systems, and exergetic loss minimization through a low temperature heat supply circuit for the pools contribute to optimizing waste heat utilization and energetically optimizing the overall concept.

The cascaded use of three compression heat pumps is designed to leverage different temperature levels, optimizing coefficients of performance (COPs) while minimizing mixing of high and low return temperatures. Additionally, optimized, stratified cold and heat storage systems aim to increase system efficiency and operational flexibility, ensuring high exergetic efficiency. The cascaded heat pump setup enables the provision of water at temperatures of 40 to 50°C from wastewater from the thermal baths, waste heat recovery from climate cold water, and heat recovery from the drinking water source. With an integrated intelligent control strategy, high self-consumption of PV electricity (for the thermal baths, hotel, and heating plant) or grid support operation becomes in the next steps feasible. This recovered heat is utilized to preheat the thermal water and domestic hot water.

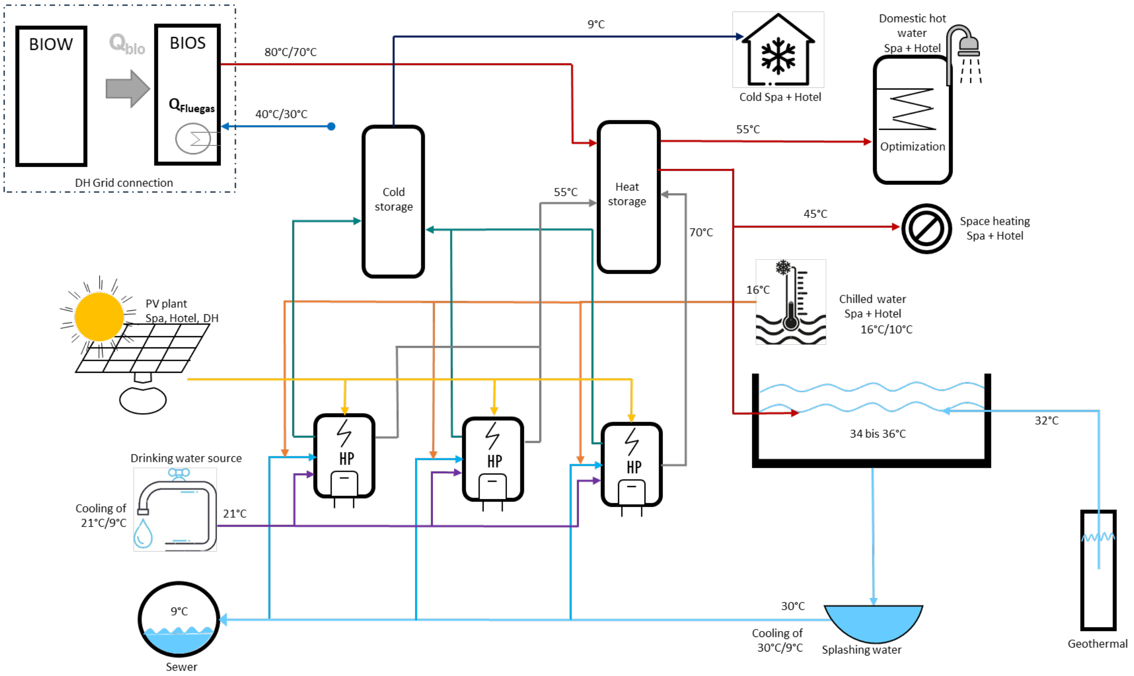

Figure 6: *Schematic overview of the energy system concept at H2O Hotel-Therme in Bad Waltersdorf*

In addition to building simulations of thermal bath and hotel for energy demand management, the energy management system shown in Fig. 6 is optimised in a Python-based model. The focus here is on heat management and electricity with the overall goal to realise an efficient and cost-effective energy strategy adaptable to climate change and cost fluctuations until 2050.

Overall, it should be noted that targeted potential analyses based on the existing framework conditions of the thermal spas are necessary, as existing supply systems and infrastructures diverge and therefore the concept development must also be adapted to the requirements.

4 Conclusion and Outlook

The exploration and implementation of innovative energy solutions in Austria's thermal bath facilities demonstrate significant potential for reducing carbon emissions and increasing energy efficiency. Through the optimization of existing infrastructure, utilization of untapped waste heat sources, and integration of renewable energy technologies, these facilities can play a pivotal role in the country's decarbonization efforts. The case studies of Sonnentherme Lutzmannsburg and H2O Hoteltherme show how diverse approaches can be tailored to specific facility needs, leading to substantial reductions in energy consumption and CO_2 emissions.

The GEO.MAT project presents first concept results for transforming thermal baths into carbon-neutral and energy-efficient facilities. Initial calculations and scenarios underscore the benefits of dynamically optimizing the entire energy system. Moreover, integrating future energy scenarios into the optimization process serves to validate the system. The next steps entails extending dynamic optimization into predictive control modeling and data predictive control modeling. Through the integration of innovative technologies and optimization strategies, the project aims to revolutionize energy management in thermal bath complexes, paving the way for sustainable practices within the tourism industry.

Additionally, ongoing collaboration between industry stakeholders, researchers, and policymakers will be crucial in fostering the widespread adoption of sustainable energy practices in thermal bath facilities across Austria and beyond. By embracing these opportunities, the thermal bath sector can continue to lead the way towards a more sustainable and environmentally friendly future.

Data availability statement

The authors do not have permission to share detailed data.

Author contributions

Carina Seidnitzer-Gallien: Conceptualization (lead), Concept development (support), Formal analysis, Methodology, Potential analysis, Visualization, Project management, Writing – original draft & review (lead), Demo H2O (lead), Demo Sonnentherme (support). **Roman Stelzer**: Potential study, Concept development, Demo Sonnentherme (lead), Methodology, pilot scale, Visualization (support). **Sebastian Dragosits**: Potential study, Visualization, Demo Sonnentherme Lutzmannsburg (support),

Competing interests

The authors declare that they have no competing interests.

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