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"Monitoring and lessons-learned of an 800 kW sector-coupling heat pump from wastewater to district heating in Gleisdorf"

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Abstract

The use of wastewater as a local energy source is gaining relevance as part of broader efforts to decarbonize heating systems and transition toward more sustainable energy solutions. In this context, a large-scale heat pump system with a thermal capacity of 800 kW_{th} was implemented at the wastewater treatment plant (WWTP) in Gleisdorf, Austria, to recover heat from wastewater and supply the district heating (DH) network via a newly built 1 km long DH pipeline.

To assess the overall performance of the heat pump system, a comprehensive monitoring concept was developed and applied from the start of operation. Furthermore, a digital dashboard was implemented to intuitively monitor the measured data, as well as key performance indicators, and identify challenges during operation. This approach aimed to evaluate the success of implementation, build operational knowledge, and identify areas for improvement, recognizing that informed decision-making is only possible with high-quality data and long-term evaluation.

During the one-year monitoring period, which was evaluated within the project "Fossilfree4Industry", the heat pump generated a total of 3,780 MWh of thermal energy to the buffer tank and 3,500 MWh were fed into the DH network with an average feed temperature of 79°C. This is close to the design target of 4,320 MWh/year. The planning benchmark for the seasonal performance factor (SPF) was 2.65, estimated by averaging monthly calculated coefficients of performance (COP). This benchmark was closely approached by the implemented system, which achieved a SPF of 2.58 over the monitoring period. In conclusion, the heat pump integration demonstrates stable and efficient performance under real operating conditions.

Keywords: heat pump; sector coupling; district heating; wastewater treatment plant;

1. Introduction

As cities aim to decarbonize and enhance energy efficiency, wastewater treatment plants (WWTPs) represent an underutilized but promising renewable energy source. Municipal wastewater retains a considerable amount of low-grade heat even after treatment, which can be effectively recovered through heat pumps integrated into district heating networks.

For the EU-28 at the time of the study (EU-27 plus the United Kingdom), Persson et al. [1] presented in a revised report of 2020 the results of the ReUseHeat project analyzing the potential of utilizing wastewater as a heat source. It builds on the Waterbase dataset of the European Environment Agency with the latest version being published in October 2025 [2]. Previous versions of the database were also the basis of [3], [4], [5]. In [1] a regression model was developed based on 18 Swedish existing wastewater heat pump systems with a combined total 159 data years. The results for the EU28 show for 23,189 WWTPs (Austria: 634) an excess heat potential (assuming a COP of 3) of 317 TWh/a (Austria: 8.6 TWh/a).

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Lygnerud et al. [3] builds on the dataset and narrows the potential down to accessible heat by limiting the number of systems to WWTPs which are within two kilometers from a district heating network. This brings the number of WWTPs down to 2,617 and the accessible heat yield to 138 TWh. Mathiesen et al. [5] build on earlier versions of the report [1] and estimates a wastewater heat potential of 511 TWh/a for the EU28 by 2050.

In Austria, Neugebauer et al. [6] performed a spatial analysis of 632 WWTPs, estimating a wastewater heat potential of 3.19 TWh/a assuming a COP of 4, 4,500 full-load hours, a temperature reduction of 5 K, and a 30% reduction due to flow variability. Of this potential, 72% was identified as spatially suitable for heat extraction. Applying the same methodology, Hammer et al. [4] extended the analysis to an Austrian-wide heat cadaster, estimating wastewater heat potentials of 4.1 TWh in 2019 and 4.3 TWh by 2040.

WWTPs provide a reliable and stable heat source while contributing to broader objectives of energy sector coupling and circular economy strategies. This formed the basis of a 2020 planning study by Gruber-Glatzl et al. [7] for the same WWTP use case. The present work builds on this by comparing planning-stage estimates with monitored system performance.

2. System Description

To evaluate the performance of hybrid energy systems such as wastewater heat pump installations, a dedicated monitoring system is required. Data from defined measurement points are transmitted to a central database and analyzed to assess system operation, control strategies, and potential malfunctions, forming the basis for reliable operation and optimization.

The wastewater treatment plant (WWTP) Gleisdorf (Styria, Austria) serves approximately 32,000 population equivalents and treats about 2.0 million m³ of wastewater per year from seven municipalities. Prior to system integration in 2018, the site had no natural gas or district heating grid connection. Energy supply relied on biogas production of approximately 80 kW from a 480 m³ digester, primarily used for digester heating and space heating of WWTP buildings, with excess biogas flared during summer months.

In parallel, the local district heating operator Stadtwerke Gleisdorf evaluated future supply scenarios. Schrammel et al. [8] demonstrated that a significant share of natural gas consumption could be replaced by renewable heat sources, including biogas and wastewater-based heat pumps. Building on this, several heat pump integration options were analyzed by Gruber-Glatzl et al. [7], highlighting techno-economic trade-offs between thermal capacity and supply temperature. Of the three concepts evaluated, the 'Parallel Heating' configuration, in which the heat pump directly supplies the district heating network temperature level, was chosen for detailed engineering and implementation. The system configuration is illustrated in Figure 1.

The installation comprises a wastewater-source heat pump with a maximum thermal output of 800 kW_{th}. On-site photovoltaic and nearby hydropower complement the renewable system in the proximity of the WWTP. Biogas utilization options were evaluated in [7] too, resulting in the implementation of a new biogas boiler integrated into the overall system concept. The WWTP is connected to the city's district heating (DH) network via a 1,000 m connection line operating at supply temperatures of 75–80 °C and return temperatures

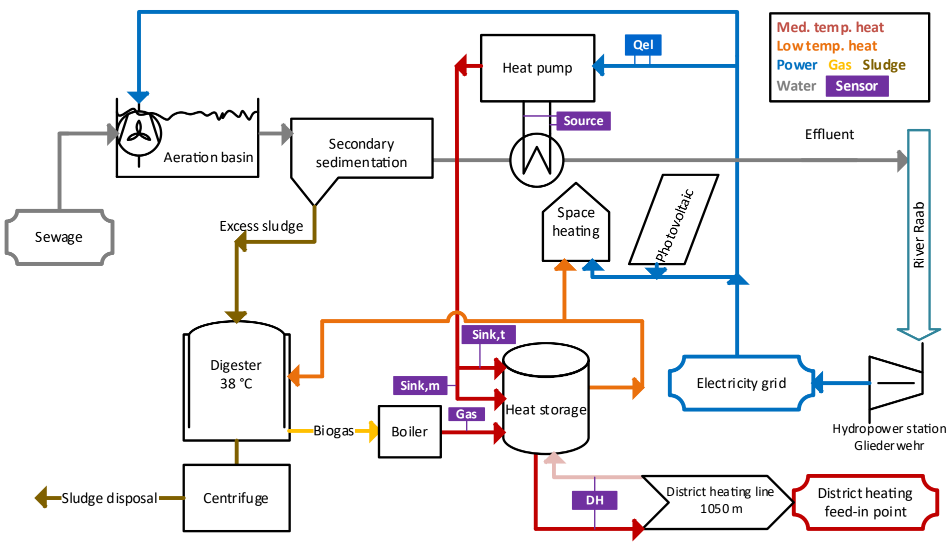

Figure 1: Implementation concept for HP at the WWTP, sensors are explained in detail in Table 1 (Source: AEE INTEC).

of 48–52 °C. The combined system increases operational flexibility of the DH network, enabling full heat supply from the WWTP during summer and flexible load coverage by the heat pump and biogas system during winter. A comprehensive monitoring framework was implemented from the start of operation to assess system performance [9]. The methodology and results are presented in the following sections.

3. Methods/Approach

3.1 Monitoring approach

A monitoring system consists of sensors positioned at defined points within the energy system, a datalogger that records the data from the installed sensors, and a central database where the data are stored and can be used for analysis and visualisations. These systems require a monitoring concept, which is defined at the beginning of the process. This concept specifies the plant assessment – for example, an energy balance between input and output. Subsequently, the measurement points required for analysis are defined in the hydraulic scheme. The most common measurement points include temperature sensors, heat meters (energy valves), electricity meters, and pressure sensors. To assess energy transport within the plant, pump control signals and valve positions are also recorded.

All sensor data are recorded in the plant's internal control system, from which they are transmitted on-site via BacNet and ModbusTCP to a Programmable Logic Controller (PLC). This PLC then sends the data via a File Transfer Protocol (FTP) protocol to a ThingsBoard data server, which is located at AEE INTEC. ThingsBoard is an open-source Internet of Things (IoT) platform on which the data are stored and ultimately visualized and analysed [10].

The relevant sensors are indicated in Figure 1 with filled-out rectangles and explained in more detail including type of sensor and measured variables in Table 1.

Table 1. Overview of relevant sensors for monitoring (Source: Stadtwerke Gleisdorf, AEE INTEC).

Sensor name	Type of sensor	Measured variables and corresp. units
DH Gas Sink,m Sink,t Source	Energy valve (Producer: Belimo) *Note: Each of the 5 sensors listed left measures the 5 variables listed right.*	Heat quantity - Q (kWh) Flow temperature - T_{flow} (°C) Return temperature - T_{return} (°C) Power - P (kW) Volume flow - $\dot{V}$ (m^3/h)
Qel (includes Qel_{HP12} and Qel_{HP22})	Electric meter	Consumed electricity - Qel (kWh)

3.2 Energy balance calculation

To evaluate the key performance indicators (KPIs) for the heat pump (HP) integration, first the energy balances across the HP and the buffer tank need to be compiled. To validate the measured data several approaches involving different measurement points were performed. The calculations are shown exemplary for the amount of heat taken from the source. Since the measurements are done every minute the sum up to time n needs to be divided by 60:

1) The measured amounts of heat in- and output were provided through a heat meter in the energy valves.
2) The amounts of heat in- and output were calculated using the measured power through the power meter in the energy valves. As there were measurement values captured each minute, so 60 measurements per hour, the sum of the power was divided by 60 to obtain the total amount of heat.

$$Q_{source} = \sum_{t=1}^{n} P_{source} / 60 \quad (1)$$

3) The flow rate and the temperature difference between flow and return line were used to calculate the amounts of heat in- and output for compiling the energy balances – this was used for the energy balances shown in the results. It was divided by 60 for the same reason as explained for Eq. (1).

$$Q_{source} = (\sum_{t=1}^{n} \dot{V}_{source} / 3.6 * c_{p,water} * (T_{source,flow} - T_{source,return}))/60 \quad (2)$$

This methodology helped to identify some incorrect and faulty measurements towards the end of the year concerning the heat meters; thus, the other routes were utilized for the energy balances. The energy balance for the HP was compiled as follows:

$$Input_{HP} = Q_{source} + Qel_{HP12} + Qel_{HP22} \quad (3)$$
$$Output_{HP} = Q_{sink,m} + Q_{sink,t} \quad (4)$$

The energy balance for the buffer tank was calculated as follows:

$$Input_{buffer} = Q_{sink,m} + Q_{sink,t} + Q_{gas} \quad (5)$$
$$Output_{buffer} = Q_{DH} \quad (6)$$

The COP was calculated by dividing the thermal output of the heat pump delivered to the buffer storage by the electrical power measured at the two electricity measurement points:

$$COP = (Q_{sink,m} + Q_{sink,t}) \,/\, (Qel_{HP12} + Qel_{HP22}) \quad (7)$$

4. Results and Discussion

For the evaluation of system performance, energy balances across the heat pump (HP) and the buffer tank were established as per the calculation explained in Section 3.2 and the results were summarized in Table 2. The HP is supplied by thermal energy extracted from the wastewater via a heat exchanger (Q_{source}) and powered by two electrical inputs (Qel_{HP12} and Qel_{HP22}) corresponding to the two compressor circuits. Supplementary electricity demands for the source water pump are not included the energy balance. The generated heat is transferred to the buffer tank through two inlets positioned at the top ($Q_{sink,t}$) and the middle ($Q_{sink,m}$) of the tank. To meet the DH requirements for the feed temperature heat was mostly integrated into the upper section. This can be observed in the resulting amount of heat per position as showcased in Table 2.

Periods of system downtime, identified by the absence of heat flow from the source ($Q_{source} = 0$), were excluded from the overall balances. However, partial-load operation is included.

The energy balance of the buffer tank also considers a potential contribution from biogas combustion (Q_{gas}), representing the thermal energy generated by the on-site biogas boiler. As the biogas boiler was not operational during the monitoring period and thus did not supply any heat to the buffer tank, this component is included in the energy balances for completeness but does not influence the reported results and is therefore not listed in Table 2. Over the monitoring period, the HP supplied a total of 3,780 MWh of thermal energy to the buffer tank. During the first year of operation, the buffer tank delivered a total of 3,500 MWh of heat to the district heating (DH) network ($Q_{buffer,DH}$) at an average temperature of 79 °C.

The system was designed for an annual output of 4,320 MWh [9], which compares favorably with the measured production of 3,780 MWh, considering downtimes and partial-load operation during the initial ramp-up phase. In contrast, commonly used wastewater heat potential assessments predict substantially higher theoretical values for the WWTP in Gleisdorf: the methods applied in [4] and [6] estimate a potential of 11,720 MWh, while the regression-based model proposed in [1] yields 17,071 MWh. These potential estimates exceed the monitored production, which is consistent with the current system design as it only uses a partial flow of the wastewater. Consequently, the heat pump system is suitable for expansion as discussed in the outlook.

The heat pump operated for 7,732 hours, corresponding to 88% of the total observation period (defined by $Q_{source} > 0$). Assuming a nominal thermal capacity of 800 kW, the measured production of the one-year period corresponds to 4,725 full-load hours, which is in good agreement with the assumption of 4,500 full-load hours reported in [6]. Heat losses from the buffer tank amounted to 7.4% of the total thermal input.

To derive representative KPIs for stable operation phases, two additional time intervals were analysed separately: a winter period (15 December 2023 – 4 January 2024) and a spring period (4 April 2024 – 6 May 2024) (results are also shown in Table 2). These periods were characterized by higher thermal output of the heat pump, reflecting its increased performance and the specific needs of the DH network during these periods.

In the conceptual phase in 2020 and presented in [7], the SPF was estimated by averaging monthly COP values derived from operating points reflecting seasonal variations in wastewater temperature. Applying the same method, a benchmark SPF of 2.65 is obtained. The monitored system performance yields an SPF of 2.58, which is in very good agreement with this planning estimate for the recorded average source and sink temperatures over monitoring period. The PPF (periodic performance factor) values for the separately analyzed periods are slightly lower, amounting to 2.44 for the winter period and 2.54 for the spring period.

Table 2. Overview of relevant KPIs for various operation periods (Source: Stadtwerke Gleisdorf, AEE INTEC).

KPI	Unit	**1 year**	**20 winter days**	**33 spring days**
		August 23 – July 24	15.12.23-04.01.24	04.04.24-06.05.24
Thermal input from source (wastewater, Q_{source})	MWh	2,008	184	260
Electrical power input HP (Qel_{HP12} + Qel_{HP22})	MWh	1,471	133	177
Total heat from HP to buffer tank ($Q_{sink,t}$ + $Q_{sink,m}$)	MWh	3,780 (3,677 + 103)	325 (325 + 0)	450 (450 + 0)
Total heat fed into the DH network ($Q_{buffer,DH}$)	MWh	3,500	316	439
Average temperature of the source (wastewater)	°C	14.9	11.3	14.2
Grid temperature supply average value	°C	79.0	83.2	79.1
Grid temperature return average value	°C	52.6	52.2	52.8
Seasonal/Periodic performance factor (SPF/PPF)	-	2.58	2.44	2.54

While the SPF/PPF in Table 2 summarizes the overall efficiency of the heat pump over the three observed time periods, Figure 2 analyzes the COP (Coefficient of Performance) under different operating conditions as a function of wastewater temperature. First, the dataset was filtered to include only operating points close to the nominal volume flow rates to restrict analysis to full-load conditions. Second, COP values exceeding 4 were excluded, as preliminary box plots indicated that the relevant COP range is confined to this interval, which is also consistent with practical experiences. Finally, the COP data was categorized by wastewater temperature and COP range and visualized as a heat map.

	Waste water temperature T_(source,flow)														
COP	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0<COP<=0,5	5	7	2	8	6	7	23	27	17	9	14	35	17	13	26	21
0,5<COP<=1	21	9	7	13	10	19	23	37	25	23	12	18	29	40	29	47
1<COP<=1,5	30	17	21	16	39	39	45	45	78	184	30	35	39	58	67	65
1,5<COP<=2	216	149	179	614	1737	1825	164	122	113	96	72	66	73	78	114	61
2<COP<=2,5	2601	25064	23260	22221	33068	7221	1141	7002	4003	3637	2802	2326	2008	954	649	71
2,5<COP<=3	3529	23246	7126	2186	1142	967	973	8349	4641	2771	3296	7313	5203	8071	7164	2710
3<COP<=3,5	86	350	204	146	91	101	118	379	311	190	253	336	286	356	382	96
3,5<COP<=4	22	33	63	40	27	47	43	92	164	80	108	123	138	113	160	48

Figure 2: Heat map showing the frequency of COP depending on wastewater temperature ($T_{source,flow}$). Numbers represent minutes of occurrence, with green indicating higher frequencies. (Source: Stadtwerke Gleisdorf, AEE INTEC).

For wastewater temperatures equal and below 10 °C, COP values predominantly range between 2.0 and 2.5 (72% of time), whereas for wastewater temperatures above 10 °C, COP values are mainly between 2.5 and 3.0 (62% of time). Anomalously high COP values observed at a wastewater temperature of approximately 6 °C are interpreted as likely measurement artifacts and require further investigation. Two possible reasons for an observed COP below 1 are: (a) Delay in measurement where heat derived from wastewater is already detected or the heat pump is already utilizing power ($Q_{source} > 0$ or $Qel > 0$), but no heat is transferred into the buffer tank in the same time stamp ($Q_{sink,t}$ and $Q_{sink,m} = 0$), which can occur during ramp-up of the HP; (b) Power measurement Qel only updates every four minutes unlike the other measurement points and therefore sometimes mismatches occur that result in a low COP.

5. Conclusions and outlook

The successful HP integration confirmed that wastewater heat recovery is technically feasible, though distance to DH connection points, required DH flow temperatures and thermal load profiles remain limiting factors. The concept also demonstrated that close coordination between WWTP and DH operators is essential, as WWTPs can evolve from self-sufficient facilities into active energy hubs linking water, heat, electricity, and gas networks within a carbon-free regional energy system.

Wastewater represents a substantial heat source for district heating networks. While many potential studies assume COP values between 3 and 4, the present analysis yields an SPF of 2.58 for an 80 °C DH network, indicating that more conservative performance assumptions may be appropriate for planning.

Based on the remaining theoretical wastewater heat potential at the site, the installation of an additional 2 MW heat pump could be considered in a future system expansion, consistent with existing potential studies and preliminary considerations of the operator.

Due to the increasing energy demand of the district heating network, the generation unit at the WWTP Gleisdorf site was expanded in a second development stage with a 4 MW_{th} biomass boiler and an additional 200 m³ buffer tank. In the new hydraulic concept, the heat pump is integrated in the return line of the DH. This concept enables the heat pump to operate at lower sink temperatures and thus higher efficiency and supports future system optimization and expansion.

Consequently, the monitoring concept was adapted within "Fossilfree4Industry" to updated boundary conditions. Experience from the initial monitoring phase led to improvements during the second development stage, including the replacement of energy valves with heat meters and a change in data transmission from Modbus TCP to Modbus RTU. The resulting setup enables more detailed performance comparisons of hybrid energy systems under real operating conditions in future.

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