15TH IEA HEAT PUMP CONFERENCE
MAY 26–29, 2026 | HOFBURG
VIENNA 2026
DECARBONISATION THROUGH INNOVATION

Transformation plan for a district heating towards a climate-neutral heat supply

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Abstract

A district heating network in western Germany, is undergoing a systematic transition from a fossil-based to a renewable and climate-neutral heat supply. The current network covers approximately 20 km, serving around 230 customers with an annual heat demand of about 18,000 MWh. The transformation became necessary following the decommissioning of a coal-fired power plant and the upcoming end of the current industrial waste heat contract with a local industrial company

The transformation plan was developed by enerbasics, in collaboration with the heat supplier and the local city council. A structured evaluation of ten renewable and alternative heat sources was conducted, including surface water, sewage heat, geothermal energy, solar thermal, pyrolysis, and ambient air heat pumps. The methodology combined technical feasibility studies, hydrological assessments, thermodynamic modelling, and economic analysis.

The results identified a multi-technology approach as the most promising. The selected configuration is based on a 4 MW air-source heat pump with 3,000 m^2 thermal storage tank covering approximately 70% of the heat demand. For peak loads a 5 MW combined heat and power plant H2-ready (CHP), and a 5 MW power-to-heat (PtH) unit. providing additional flexibility and system stability. To reduce thermal losses, the maximum network supply temperature was successfully lowered from 120°C to 95°C.

The concept foresees the integration of locally produced renewable electricity from an existing wind turbine and planned photovoltaic systems on industrial rooftops. The network expansion is planned in stages, combining targeted densification within the existing network area and strategic network extension to adjacent districts and new developments. The transformation plan foresees phased implementation between 2025 and 2045, providing a practical and replicable model for municipalities aiming to decarbonize their district heating systems.

1. Introduction

District heating networks play a central role in Germany's transition to climate-neutral heat supply systems. In urban areas such as the Ruhr area, district heating is particularly valuable due to the diversity of connected customers and the ability to integrate large-scale renewable energy sources. The district heating system supplies approximately 230 end users across multiple segments, including residential buildings, industrial consumers, public institutions, and municipal facilities. The annual heat consumption in 2022 was approximately 18,542 MWh, with a contractual connected load of around 13 MW and a peak load of 10 MW.

Historically, the network was supplied by a coal-fired power plant, which was decommissioned in 2014. After its closure, heat supply transitioned to industrial steam from a global producer of carbon-based industrial materials. This arrangement, while operationally functional, does not satisfy long-term ecological or political requirements, especially in light of Germany's climate legislation and the mandatory municipal heat planning framework.

The transformation of the network must therefore address not only the shift toward renewable heat supply

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15th IEA Heat Pump Conference 2026 - THN6.1 - https://doi.org/10.23697/54y9-hw54

but also modernization of aging infrastructure, temperature reduction strategies, customer expansion opportunities, and integration with regional hydrogen infrastructure. This paper presents the complete transformation concept developed in 2025.

2. Methods and Approach

The transformation plan was developed through a structured, multi-stage methodology combining technical analysis, simulations, forecasting, and stakeholder consultation.

2.1. Assessment of Existing Infrastructure

A detailed inventory was conducted, covering:

- Heat generation systems at a Carbon industry site
- Steam-to-water heat exchanger configuration
- 19.4 km district heating network, with mixed pipe technologies
- Existing customer structure and consumption profiles
- Historical operating temperatures and pressure conditions

2.2. Customer and Demand Analysis

Heat consumption was evaluated using:

- Actual consumption data from 2022
- NRW Heat Cadastre (LANUV) building-level heat demand profiles
- GIS-based analysis of densification and extension areas

Two categories were defined:

1. Densification potential – buildings located adjacent to existing pipes
2. Network extension potential – areas requiring new pipe routes

Projected heat demands were calculated for 2030, 2035, 2040, and 2045.

2.3. Site Assessment

Sitings were evaluated considering:

- Distance to heat network
- Access to 10 kV grid
- Wind turbine connection potential
- Proximity to hydrogen core network (“Wasserstoffkernnetz”, KLN053-01 section)
- Municipal development plans

The final selected location accommodates future hydrogen integration and renewable connections.

3. Results and Discussion

3.1. Assessment of Renewable and Waste Heat Potentials

Several options for greenhouse-gas-neutral heat generation were identified within the district heating area. The basic heat potentials were recorded in an initial screening. A detailed technical and economic evaluation will be carried out within Transformation Plan Module 1.

3.2. Surface Water – Rhine-Herne Canal

Investigation of a water-source heat pump at the Rhine-Herne Canal (RHK), considering technical, legal, and hydrological aspects.

- Former cooling-water intake (km 41.253) is in poor condition; the abstraction permit (1,220 m³/h) expired in 2016.
- Deconstruction of the intake structure is scheduled from 2026.
- Any new use requires a shipping and waterways police permit (ssG).
- Minimum extraction temperature: 8°C (to avoid critical cooling and potential ice formation).

- Temperature data from DEK Datteln used as proxy; similar conditions expected.

Hydrological Framework
- Canal section behaves largely as a quasi-static water body (standing water).
- Water exchange dependent on lock processes, pumping operations, and precipitation.
- Exact flow rates cannot be predicted reliably.

Two Options Considered
Recirculation into the Canal
- Extracted water must not fall below 8°C.
- Re-injection point must be at least 500 m downstream.
- A 5-MW heat pump would cool the canal by approx. 1 K in ~20 hours.
- Below 10°C, stable operation becomes unlikely.
- Over the past three years, temperatures were below 8°C on ~114 days/year.
- Practical maximum heat-pump capacity: ~3.5 MW.
- Feasible heat-pump share under assumptions: ~50% of annual heat generation.

Discharge into a local small river
- Limiting factor: minimum heat-pump inlet temperature ~7°C (frost protection at heat exchanger).
- Higher extraction volumes possible but subject to costly water rights and WSV fees.
- Operation unavailable on ~27 days/year.
- Maximum feasible heat-pump capacity: ~5.5 MW.
- Required discharge: ~531 m^3/h into the river.
- Achievable heat-pump share: ~80% of annual heat generation.

Conclusion
- High regulatory barriers, temperature constraints, structural risks, and deconstruction plans (2026) make canal-water utilization **not feasible** for this project.

3.3. Wastewater Channel

- Discussed with channel operator
- All wastewater channels in the city have insufficient flow rates.

Conclusion:
No wastewater channels suitable for district-heating heat extraction.

3.4. Industrial Waste Heat

- Waste-heat potentials identified using the Federal Waste Heat Platform (BfEE data as of Jan 2025).

Conclusion:
None of the identified waste-heat sources are suitable.

3.5. Geothermal Energy (Mine Water / Deep Geothermal)

Former mine gas borholes
- 391 m borehole (2007) for mine-gas extraction; closed in 2015 and filled to −300 m.
- -It was confirmed borehole is fully decommissioned → no geothermal potential.

Other Shaft Systems
- Previous geothermal assessments concluded:
    - Uncertain long-term mine-water management.
    - Technical condition insufficient.
- Not suitable for geothermal use.

Conclusion:
Neither site suitable for geothermal heat.

3.6. Ambient Air

- Everywhere available heat source; no drilling or water permits required.
- Efficiency dependent on outdoor temperature; COP decreases at low ambient temperatures.
- Large buffer storage recommended to stabilize heat-pump operation.

Conclusion:
Ambient air is a viable and practical heat source, especially when low-cost renewable electricity is available.

3.7. Solar Thermal

- Potential sites: former power plant areas.
- Solar thermal competes with PV + heat pump solutions.
- Concept developed with a manufacturer:
  - 25 ha solar-thermal field
  - 44,000 m³ seasonal storage
  - ~50% annual heat coverage
- Smaller systems also analysed.

Conclusion:
Compared to PV + heat pump, solar thermal offers lower flexibility and only partial seasonal coverage → **not pursued further**.

3.8. Pyrolysis

- Thermochemical process (500–700°C, low oxygen) converting biomass into biochar, pyrolysis gas, and usable waste heat.
- CO_2 is permanently bound in the solid biochar (negative emissions).
- NOVOCARBO operates such plants; feedstocks: clean waste wood (A1/A2), future potential for treated wood and sewage sludge.
- Business model:
  - CO_2 certificates via biochar
  - Sale of biochar (e.g., sponge-city concepts)
  - Sale of industrial waste heat (up to ~120°C)
- Concept for the district heating grid:
  - 3 pyrolysis units
  - Rotating maintenance (5 days every 3 months)
  - Space requirement: 6,000–8,000 m²
  - Approval: simplified permit procedure (~1 year, 4th BImSchV)
  - Minimum economic load ~1.5 MW (summer demand).

Conclusion:
Pyrolysis is innovative and climate-positive, but dependency on a third-party operator and uncertain feedstock costs reduce feasibility.

3.9. Power-to-Heat (PtH)

- Converts excess renewable electricity into heat for district heating.
- Useful for grid stability and improving CO_2 performance.
- For systems ≤10 MW, direct electric boilers / instantaneous heaters are cost-effective and easy to integrate.
- Electrode boilers also possible.

Conclusion:
PtH provides valuable flexibility, particularly when combined with thermal storage.

3.10. Combined Heat and Power (CHP)

- CHP units provide simultaneous heat and electricity.
- Supported by the KWKG, attractive in short term.
- Considered a transition technology toward long-term GHG neutrality.

- New units typically H_2-ready.

Conclusion:
CHP remains a useful complementary heat source.

3.11. Thermal Energy Storage

- Use of a low-pressure, single-zone water storage tank (<100°C).
- Simpler design than two-zone high-temperature tanks.
- Storage analysis based on 2023 load profiles:
  - <2000 m³: too many charge/discharge cycles
  - Optimal operation at 4 MW charging/discharging
  - Larger generation → less storage use
- 3000 m³ storage smooths network peaks and covers most loads.

Conclusion:
A 3000 m³ storage combined with 4 MW heat generation ensures flexibility and stable operation of modern heat-generation systems.

3.12. Future Heat Generation Concept

3.13. Air-to-Water Heat Pump (4 MW)

Ambient air was identified as the only renewable heat source capable of delivering multi-MW capacity. Alternative sources such as wastewater or river water were evaluated but excluded due to insufficient potential or impractical siting.

Key characteristics:

- 4 MW thermal output
- Ammonia (NH_3) refrigerant
- V-shaped air collectors with 22 fans each
- COP ~ 2.6 annual average
- JAZ 2.59
- ~9,500 MWh heat per year
- Nighttime sound-pressure limit: ≤ 67 dB(A) per fan

Due to noise constraints, nighttime operation requires reduced ventilation speeds. CFD and acoustic simulations confirmed feasibility with appropriate mitigation measures.

3.14. Thermal Energy Storage (3,000 m³)

A central component of the system is a 3,000 m³ pressurized storage tank:

- ~100 MWh usable thermal capacity
- 95°C / 65°C layering
- Acts as a hydraulic decoupler
- Enables peak-load shifting
- Provides flexibility for integrating wind-based electricity supply

Storage losses are approx. 15% over 30 days at full charge.

3.15. CHP Units (2 × 2.15 MWth / 2 × 2.0 MWel)

Two hydrogen-ready CHP units support:

- Heat-led operation with dynamic electricity optimization
- Annual heat delivery ~ 13,310 MWh
- Total system efficiency ~ 90%
- H_2-ready engines (future hydrogen or biomethane)
-

CHP remains essential for:

- Security of supply
- High electricity-price periods
- Meeting peak loads during winter

3.16. Power-to-Heat Unit (5 MW)

A PtH system offers:
- 5 MW thermal output
- Direct 10 kV connection
- Fast reaction times for grid services
- ~500 MWh annual operation (rare usage)

Function:
- Backup and redundancy
- Utilization of surplus renewable electricity
- Sector coupling capability

3.17. Forecast Heat Demand Development (2023–2045)

Annual heat demand projections:

Year	Existing Customers	Densification	Extension	Total Demand
2023	16,209 MWh	–	–	16,209 MWh
2030	16,209 MWh	1,030 MWh	1,185 MWh	18,424 MWh
2035	16,209 MWh	2,060 MWh	4,740 MWh	23,009 MWh
2040	16,209 MWh	3,090 MWh	8,295 MWh	27,594 MWh
2045	16,209 MWh	4,120 MWh	11,850 MWh	32,179 MWh

Table 1: future heat demand

Demand will nearly double by 2045, requiring:
- new generation capacity
- improved network efficiency
- modernized infrastructure

3.18. Hydraulic and Thermal Network Considerations

The current network:
- 19.4 km pipe length
- Mixed materials (KMR, SMR, Aquawarm, flexible systems)
- Supply temperature: 85–125°C
- Return temperature: 60–70°C

Hydraulic modeling confirms:
- Reduction to 95°C supply is feasible
- Lower return temperatures (~55°C) achievable with substation optimization
- Temperature reduction lowers heat losses by ~20%

Field tests (2025–2026) will validate real-world performance.

3.19. Network Modernization and Heat Loss Reduction

Current heat losses (2025): 32%
Expected reductions:
- 2030: 25%
- 2035: 23%
- 2040: 21%
- 2045: 20%

Key measures:
- Replacement of pre-1990 pipe sections

- Hydraulic decoupling of unused branches
- Transition to low-temperature operation

3.20. Siting Strategy and Renewable Integration

The selected site offers:

- Available land from 2026
- Potential connection to a future wind turbine
- Nearby roof areas suitable for PV
- Direct adjacency to the Hydrogen Core Network (KLN053-01)
- Short distance to primary heating grid

This location optimally supports:

- Renewable integration
- Future hydrogen use
- Long-term expansion corridors

3.21. Energy System Simulation

Operational simulations were performed using EnergyPro (EMD International A/S).
The model included:

- Heat pump performance curves
- Electricity price volatility
- CHP operational constraints under the KWK law
- CO_2 pricing
- Future renewable energy requirements (§29 WPG)
- Storage charging/discharging strategies

Three market scenarios were simulated to evaluate sensitivity to price fluctuations.

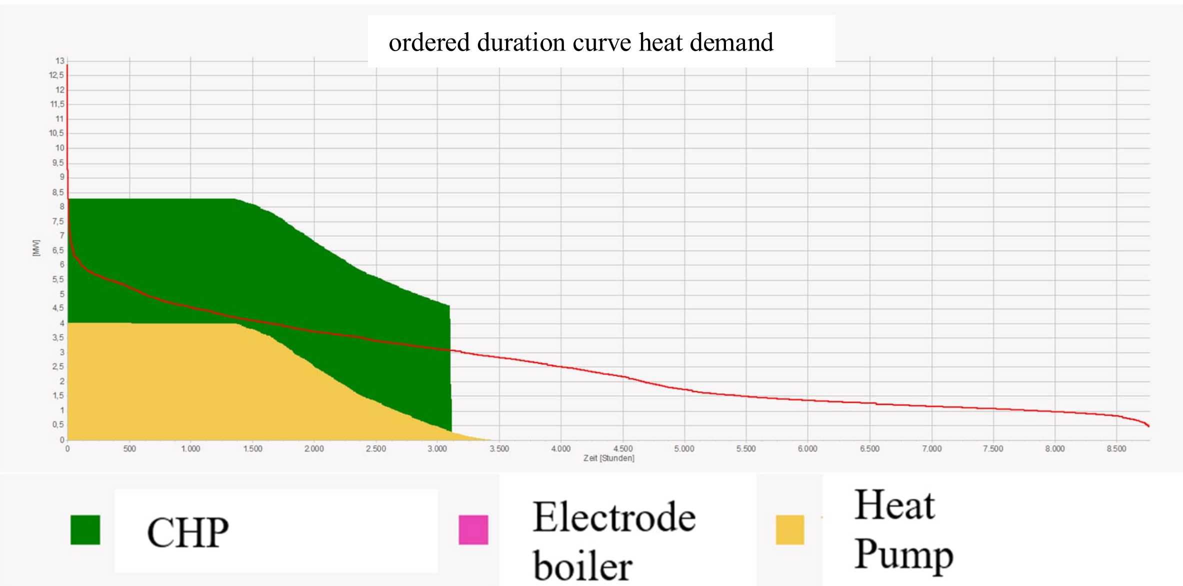

Figure 1: ordered duration curve heat demand for heat generation

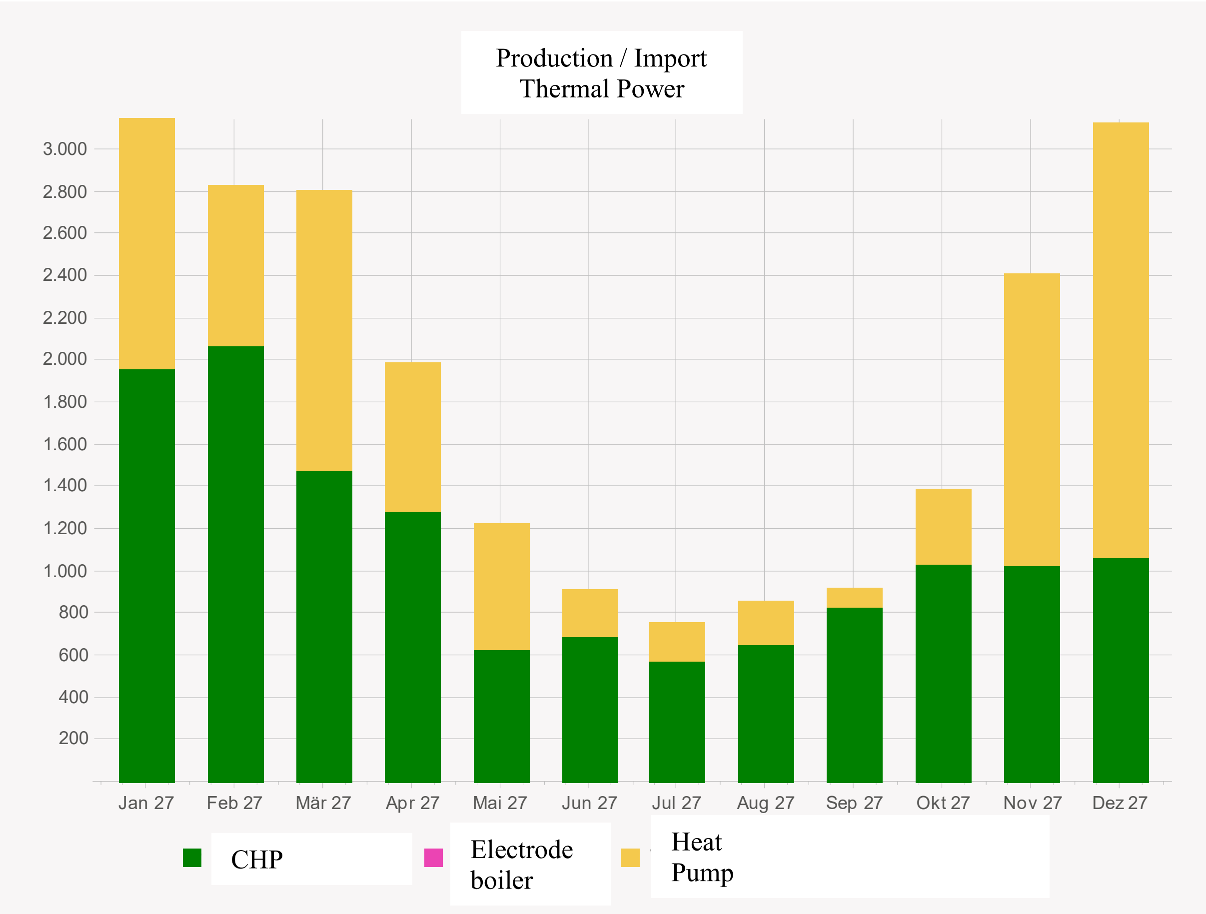

Figure 2: Heat generation throughout the year

Key findings:

- Heat pump covers >50% of annual supply
- CHP covers ~47%, depending on electricity markets
- PtH < 1% annually but critical for flexibility
- Storage smooths diurnal fluctuations
- Renewable share meets 2030 (30%) and 2040 (80%) targets

System achieves:

- High reliability
- Economic optimization
- Strong alignment with regulatory requirements

3.22. Hydraulic Modeling

Hydraulic feasibility for reducing supply temperature from 125°C to 95°C was assessed using EC-Netz. The model covered:

- Pressure losses
- Flow distribution
- Node temperatures
- Effects of temperature reduction on consumer substations
- Sector-coupling effects with the thermal storage system

Results confirmed that reduced-temperature operation is technically feasible, but additional field tests are required to ensure compatibility of all existing substations.

4. Conclusions

The transformation of the district heating system is technically feasible, economically viable, and environmentally advantageous. Through a coordinated combination of air-source heat pump technology, large-scale thermal storage, hydrogen-ready CHP units, and a PtH system, the future heat supply will meet national climate targets while ensuring security and affordability.

Hydraulic modelling confirms the feasibility of a substantial supply-temperature reduction, which, combined with targeted modernization efforts, will reduce heat losses significantly. Demand is expected to grow, but the planned multi-technology concept provides sufficient scalability and robustness to accommodate expansion.

The chosen site provides excellent conditions for future integration of wind, photovoltaic energy, and hydrogen infrastructure, reinforcing the long-term sustainability of the system.

Overall, the transformation plan establishes this project as a model case for municipal decarbonization in Germany.