Deliverable Report

Mainstreaming governance, co-investment and technology solutions for Positive Energy Districts in monument protected areas (MonuPED)

Start date of project: 01/01/2025 **Duration 36 months**

D4.2 Neighbourhood Heating Storage System in Leipzig

Workpackage 4: MonuPED toolkit - Solutions and tools

MONUPED

DUT Driving Urban Transitions

Co-funded by the European Union

Co-funders

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OVERVIEW / EXECUTIVE SUMMARY

This report outlines the development of a pioneering municipal heat storage project in Leipzig-Plagwitz, which aims to utilise the subsurface as a seasonal energy reservoir. By capturing and temporarily storing heat from predominantly renewable sources, the project demonstrates a novel, community-oriented, and climate-friendly approach to urban heating—even in densely built areas with limited space or heritage protection restrictions.

The technical foundation relies on Borehole Thermal Energy Storage (BTES), where geothermal probes exchange heat with the ground. This system not only enables efficient seasonal storage but also allows for active regeneration and bidirectional energy flow—both heat extraction and feed-in by various stakeholders, including private prosumers and strategic partners.

CENERO Energy GmbH serves as project coordinator, operator, and primary heat producer, managing contracts and system operations. The legal framework employs a hybrid contract model with usage, feed-in, and supply agreements, designed to accommodate the shared infrastructure and diverse economic roles of participants.

Key legal considerations address the applicability of district heating regulations, water law permits for groundwater use, and road law permits for public land occupation. Importantly, the system's unique prosumer-based approach does not fit neatly within existing district heating legislation, suggesting a need for tailored regulatory treatment.

The concept is also extendable to cooling supply without requiring separate legal frameworks. Economic viability is supported through optimised system design and cost-sharing among multiple participants.

Overall, this project provides a replicable model for urban energy infrastructure that fosters collaboration between city authorities, industry, and science, contributing significantly to sustainable urban heating transitions.

RECOMMENDATIONS:

- Secure substantial upfront CAPEX funding (50–60%) to ensure economic feasibility.
  Due to high initial drilling and installation costs for the BTES system, significant public funding or subsidies are essential to achieve competitive heat prices and encourage stakeholder participation.

- Develop a tailored regulatory framework that recognises the hybrid, prosumer-based structure of the system.
  Since the model does not neatly fit into existing district heating regulations, a clarified legal interpretation or customised municipal guidelines will reduce uncertainties and facilitate broader adoption.

- Strengthen collaboration between the city departments, legal and technical partners, and private stakeholders.
  Close coordination is required for permitting, land access, optimised system design, and long-term monitoring. This also enhances replicability of the concept in other urban districts.

- Implement a flexible, transparent contract model for prosumers and strategic partners.
  Standardised usage, feed-in, and supply agreements should be refined to ensure consistent technical requirements, clear responsibilities, and fair remuneration mechanisms for heat feed-in and consumption.

- Prioritise integration of waste heat and local renewable sources to reduce operating costs.
  By incorporating cooling waste heat, PV electricity, or industrial excess heat, the system can

significantly improve its efficiency by increasing the lifecycle of the probes and decrease reliance on grid electricity.

- Plan for long-term operational subsidies during the initial years of system maturity. Given the complex billing structure and early-stage uncertainties, temporary operational support will help stabilise heat prices until the system reaches optimal load and wider prosumer participation.

1 INTRODUCTION

In the western part of Leipzig, near the Baumwollspinnerei and Saarländer Straße, a municipal heat storage facility is planned that will use the subsurface as a seasonal energy reservoir. Its purpose is to capture heat from various sources—primarily renewable ones (geothermal probes and waste heat from cooling processes), though not exclusively—store it temporarily, and supply it again as needed.

The project is intended to demonstrate that a community-based and climate-friendly heat supply is possible even in densely built urban districts with limited space. Its unique feature lies in the combination of a geothermal storage system, shared use, and a prosumer structure. Heat can be both extracted and fed into the system. This creates an infrastructure that brings together different stakeholders and opens new pathways for decarbonising the urban heating sector.

Monument-protected areas and buildings often face significant constraints when it comes to implementing modern heating technologies such as solar thermal systems or other renewable heat sources, due to strict preservation regulations and the need to maintain historical integrity. These limitations are particularly pronounced in densely built central urban areas, where space for installing individual heating infrastructure is scarce or non-existent.

The communal geothermal heat storage concept offers a sustainable alternative tailored to these challenges. Monument-protected buildings can connect to a neighbourhood heating storage network that is shared with adjacent areas that are not monument protected, and where there may be more available space for geothermal probe installation. This shared infrastructure enables heritage sites to benefit from renewable, low-carbon heat without the need for intrusive modifications to their structures or surroundings.

By linking monument-protected buildings to a wider network, the system facilitates efficient heat distribution while respecting preservation requirements. This collaborative approach not only supports the decarbonisation of sensitive urban quarters but also fosters social and economic cooperation among different urban stakeholders. Ultimately, the goal is to provide a scalable and adaptable heating solution that aligns heritage conservation with modern sustainability goals.

Furthermore, the project is aligned with European and municipal strategies for the heating transition. It aims to provide a concept transferable to other cities and contribute to accelerating the shift from individual heating solutions to community-based energy systems.

2. TECHNICAL CONCEPT

The technical concept is based on Borehole Thermal Energy Storage (BTES), where the ground or underlying rock serves as a seasonal heat reservoir. Geothermal probes function as heat exchangers that charge and discharge the storage. These probes are typically designed as double-U pipes, through which a circulating fluid transports heat.

An evaluation of the areas was carried out in coordination with the owners, with the following areas being under consideration:

Figure 1: Potential areas for geothermal energy

To evaluate geothermal resource availability and potential drilling constraints, additional geological investigations, including test drilling and a Thermal Response Test (TRT), are required.

Minimising resource uncertainty through geological and seismic surveys is essential, alongside identifying suitable drilling sites. One option is using public spaces, particularly roads. Discussions with the Mobility and Civil Engineering Department revealed openness to decentralised solutions; however, there is still a lack of regulations in place and limited media and construction space means proof of feasibility on private land is required before public areas can be considered. High demand for road space, especially in densely built-up zones, adds further complexity.

Beyond the currently examined areas, additional potential sites for future expansion have been identified, with discussions with owners still pending. Given their proximity to existing heating control centre, the primary focus remains on sites within or near the Spinnerei to reduce line losses and development costs.

Table 1: Potential from Geothermal Energy in the Spinnerei area

	Amount of probes	Sum of probes in meters [m]	Potential heat extraction [MWh/a]	Potential heat generation [MWh/a]	Potential heat extraction full regeneration [MWh/a]	Potential heat generation full regeneration [MWh/a]
Geothermal analysis	167	13.409	1.055	1.477	1.609	2.253

Table 2: Data for Determining Geothermal Potential

	Amount	Unit
Distance between probes	8	m
Area per probe	64	m2
Depth of probe	80	m
Coefficient of Performance (COP) of Ground-source heat pump	3,5	
Extraction Capacity	52	W/m (for 1800 h)
Extracted Heat	93,6	kWh/m
Extracted Heat	78,7	kWh/m (partial regeneration)
Extracted Heat	120	kWh/m (full regeneration)

For the purpose of this analysis, only areas within the Spinnerei were included in the geothermal consideration, as positive preliminary discussions have already taken place in this area.

During the heating season, heat can be extracted from the ground both from what was stored during the summer and from naturally regenerated heat. The low-temperature heat collected via the probes is then elevated to a higher, usable temperature by heat pumps and distributed to connected buildings through a heating network.

In summer, the subsurface naturally regenerates through geothermal heat flows and groundwater movement. Additionally, heat can be actively fed into the ground to recharge the storage. One approach is to use the cold present in the probe field for efficient cooling (free cooling). At the same time, the waste heat generated during cooling recharges the storage. Excess heat from solar thermal systems, industrial processes, or cooling plants can also be fed into the subsurface.

This active regeneration enables significantly more heat to be extracted from the ground—relative to the size of the probe field—than passive use alone. As a result, drilling investment costs are reduced in proportion to the heat supplied.

Compared to air-source heat pumps, geothermal heat pumps achieve much higher efficiencies because the ground temperature in winter remains significantly warmer and more stable than the outside air. This leads to more efficient heat pump operation. Another benefit is the near-silent operation of the system, as no external fans are required.

Moreover, the geothermal distribution lines can be extended directly to the supplied properties, where decentralised heat pumps then raise the temperature to the required level. This approach reduces typical heat losses from district heating lines as well as associated infrastructure costs.

The drilling is planned mainly on city-owned properties in Leipzig, requiring permission for the use of public land. While the city supports the project in principle, it expects contractual agreements and compensation for land use. Since some connecting lines also cross public areas, additional permits or special usage authorisations will need to be obtained.

CENERO Energy GmbH will conduct the drilling and generate heat itself, while also enabling other stakeholders—private, commercial, and institutional—to feed heat into or withdraw heat from the storage. Consumption points can be located up to 400 meters from the central distribution point. This probe field thus forms the foundation of a shared storage infrastructure that various prosumers can join.

3. PROJECT ORGANISATION

CENERO Energy GmbH will serve as the project coordinator and operator of the planned heat storage facility. The company is responsible for planning, liaising with authorities, overseeing construction, and managing the operation of the storage system once completed. Additionally, CENERO intends to handle all contracts with participating prosumers and oversee both the technical and legal coordination.

Other key participants include the City of Leipzig, specialist firms in geothermal energy and heating network planning, scientific institutions focused on modelling thermal storage processes, as well as future users and prosumers.

4. CONTRACT CONCEPT AND SYSTEMATICS

4.1 Basic Model and Stakeholder Roles

CENERO Energy GmbH acts as the operator of the storage facility and serves as the primary heat producer.

In addition, the system can include various other participants:

- Strategic partners, such as municipal utilities or private companies, who contribute their own generation capacity or capital and take part in financing,
- Prosumers, who both consume heat from the storage and feed surplus heat back into it,
- End customers, who solely consume heat.

This model blends centralised and decentralised elements. While CENERO Energy GmbH retains full responsibility for technical operations, heat production and consumption are distributed among multiple actors. The result is an energy system that relies on shared infrastructure but accommodates diverse economic roles.

4.2 Contract Structure

The legal framework follows a hybrid model that combines a central operator structure with flexible participation forms.

(a) Contractual Relationships of CENERO Energy GmbH

CENERO Energy GmbH concludes the key contracts with the participating actors and remains the sole operator of the heat storage. These relationships can be divided into three types of contracts:

- **Usage Agreement:** This forms the legal basis for access to the shared infrastructure. The agreement governs the use of the probe field, technical requirements, measurement, data usage, and fees for infrastructure access. It corresponds to a network usage agreement in the electricity or gas sectors and defines the right to participate in the system.
- **Feed-in Agreement:** This specifies the conditions under which a participant feeds heat into the system. It regulates feed-in capacity, remuneration, priorities, and technical interfaces. For larger actors, it can be linked to investment shares or cooperation rights.
- **Supply Agreement:** This concerns the delivery of stored energy to users. The obligation to supply is subject to the actual availability of the storage. The pricing structure can include usage fees, storage fees, and capacity charges. The contracts are based on the principles of the General Terms and Conditions for District Heating (AVBFernwärmeV)[1] but are adapted to the bidirectional operating principle.

(b) Relationships Among Third Parties

There are no direct contractual relationships between smaller prosumers and end customers. Energy flows exclusively through CENERO Energy GmbH as the central operator. Strategic partners, however—where technically and regulatorily feasible—can conclude their own sales contracts with third parties. In such cases, operation and billing are conducted via the shared system of CENERO Energy GmbH.

[1] **Verordnung über Allgemeine Bedingungen für die Versorgung mit Fernwärme (Regulation on General Conditions for District Heating Supply)**

Common to all contractual relationships are the linkage of supply obligations to actual storage availability, uniform regulations for system services (measurement, data transmission, and billing), and a clear assignment of operator responsibility to CENERO Energy GmbH.

5. LEGAL FRAMEWORK

This section considers key legal issues related to energy law, water law, and road law for the project:

5.1 Applicability of the AVBFernwärmeV

A key question is whether the Ordinance on General Conditions for the Supply of District Heating (AVBFernwärmeV) applies to the relationships between the operator of the heat storage and the strategic partners or prosumers.

According to § 1 (1) AVBFernwärmeV, the ordinance applies to contracts for the pipeline-bound supply of district heating when a utility uses standardised contract templates or terms designed for a large number of cases. The ordinance is therefore aimed at traditional, long-term supply relationships, in which a district heating supplier delivers heat to numerous customers.

§ 1 (1) AVBFernwärmeV translates to: As far as district heating supply companies use standard contract templates or contract terms for the connection to the district heating supply and for the supply of district heating, which are pre-formulated for a large number of contracts (general supply conditions), Sections 2 to 34 shall apply. These shall, unless otherwise provided in paragraph 3 and Section 35, form part of the supply contract.

§ 1 Gegenstand der Verordnung

(1) Soweit Fernwärmeversorgungsunternehmen für den Anschluß an die Fernwärmeversorgung und für die Versorgung mit Fernwärme Vertragsmuster oder Vertragsbedingungen verwenden, die für eine Vielzahl von Verträgen vorformuliert sind (allgemeine Versorgungsbedingungen), gelten die §§ 2 bis 34. Diese sind, soweit Absatz 3 und § 35 nichts anderes vorsehen, Bestandteil des Versorgungsvertrages.

Figure 2:§ 1 (1) of the AVBFernwärmeV

Whether the AVBFernwärmeV applies to the planned model is uncertain. There is no existing case law on this matter, nor does the specialist literature provide detailed guidance.

However, there are strong reasons to believe that the AVBFernwärmeV does not apply: CENERO Energy GmbH intends to supply participants with heat from a jointly operated storage facility while also allowing heat to be fed back into the system. This does not correspond to the typical heat supply relationship. The operator's service is contingent on the actual availability of stored heat, and an unconditional obligation to supply heat at all times would be neither technically feasible nor legally intended.

While the provision of stored heat contains elements of a heat supply contract, the overall system differs fundamentally. It is based not on one-sided delivery, but on the mutual use of a shared infrastructure (the heat storage). Strategic partners and prosumers act as both consumers and suppliers.

Therefore, this arrangement does not constitute a typical district heating supply relationship as defined by the AVBFernwärmeV, but rather a unique usage and storage relationship. The provisions of the AVBFernwärmeV may only apply in cases where individual participants exclusively consume heat.

5.2 Water Law Permit Requirements

The installation and operation of the probe field involve the use of groundwater as defined in § 9 (2) No. 3 of the German Water Resources Act (WHG), since heat is both extracted from and returned to the subsurface. Such use requires a water law permit under § 8 (1) WHG.

The authority responsible for reviewing and granting this permit is the Lower Water Authority of the City of Leipzig. During the approval process, particular attention is given to geological conditions, borehole

sealing, the quality of materials used, and potential thermal interactions with neighbouring properties. As the boreholes are expected to be no deeper than 200 meters, the project falls under the category of "near-surface geothermal energy," meaning that a mining law procedure under the Federal Mining Act (Bundesberggesetz) is not necessary.

The water law permit will include conditions related to technical implementation, monitoring, and decommissioning. According to § 11a WHG, the thermal use of groundwater is permitted as long as it does not cause any adverse changes to its quality. This provision outlines the substantive approval criteria and confirms the general permissibility of geothermal use, provided groundwater protection is maintained.

5.3 Road Law Permit and Land Use

In addition to the water law permit under §§ 8 and 9 WHG, the installation of geothermal probes requires a special permit under road law (§ 18 of the Saxon Road Act – Sächs-StrG) whenever the drilling or pipeline connections involve public traffic areas. Water law does not supersede road law but rather complements it: while the water law permit regulates groundwater use, road law governs the occupation of public land.

The City of Leipzig has expressed general approval for such special use but expects a contractual agreement that includes a fee—typically in the form of a concession or usage permit. It remains to be determined whether the land use will be permanent or temporary, as well as the extent to which the city will maintain supervisory control over the pipeline routing.

6. COOLING SUPPLY

The concept of the municipal heat storage is fundamentally transferable to the provision of cooling. Technically, cooling is provided either by extracting thermal energy from the subsurface at low temperatures or by using reversible heat pumps. Thus, the storage can serve as a cooling source in summer and as a heat storage in winter.

Legally, there are no differences in classification. Cooling capacity is treated as thermal energy and falls under the same civil and public law framework as heat supply. Neither the AVBFernwärmeV (where applicable) nor water or road law distinguishes between heat and cooling use, so no separate permits or distinct contract types are required.

The contractual arrangements follow the same structure as for heat supply: usage, feed-in, and supply contracts also form the basis here. Adjustments are only needed for technical parameters (temperature levels, measurement, billing). This allows cooling supply to be fully integrated into the existing operator and contract model without the need for additional legal or organisational regulations.

7. ECONOMIC VIABILITY

Table 3: Costs related to district heating, geothermal systems and the existing natural gas boilers

		DISTRICT HEATING	GEOTHERMAL	NATURAL GAS BOILERS
TOTAL INVESTMENT	€	Negligible connection fee[2]	700.000	No additional investment [3]
CAPITAL COSTS	€/a	-	66.500	-
OPERATING COSTS	€/a	40.200	14.500	23.882
OF WHICH EMISSION COSTS	€/a	2.378	-	3.770
EMISSIONS	t/a	46	-	69
TOTAL COSTS	**€/a**	**40.200**	**81.000**	**23.882**

When considering heat generation costs alone, it becomes evident that geothermal energy is economically difficult to justify. This is due to the high level of required investment. For a heat output of 290 MWh, the investment is estimated at around EUR 700,000. This includes the installation of the geothermal probes, the connection piping, as well as system filling and hydraulic regulation. In addition, a heat pump is installed to cover the heat demand and integrated accordingly into the building.

For calculating capital costs, a debt ratio of 70% and an interest rate of 4.5% p.a. are assumed. Depreciation of the geothermal system is also considered. For the purpose of estimation, the depreciation period was limited to 20 years; however, it should be noted that the geothermal probes will have a significantly longer economic service life. According to VDI[4] 2067, a geothermal probe is assigned a calculated useful life of 50 years.

For the other types of heat supply, it is currently assumed that no significant investment amount will be required. When connecting to Leipzig's district heating network, typically no or only a small connection fee (approx. EUR 5,000) applies; this is difficult to generalise and was therefore disregarded in the analysis due to its limited significance.

Continued operation of the existing gas boiler system is assumed, as replacing or upgrading it in the coming years will be challenging due to its inconsistency with the City of Leipzig's goal of achieving climate neutrality by 2040. Therefore, reinvestment in a gas boiler is excluded, and a hybrid solution (gas boiler plus heat pump) is also not considered. In terms of operating costs, the geothermal solution is already the cheapest option. This is due to its high efficiency—a COP of 4 was assumed for the analysis—and to the electricity price level (EUR 0.20/kWh net). Further optimisation potential exists using on-site PV electricity and the integration of waste heat. The operating costs of the district heating option are around 270% higher than those of geothermal. In addition to the pure energy price of EUR 120/MWh, a basic fee of EUR 45/kW and a connected load of 120 kW were included. This basic fee allows the district heating provider to refinance its investment and maintenance costs. Thus, the high operating costs partially offset the lack of investment costs noted in the first section.

[2] When connecting to Leipzig's district heating network, typically no or only a small connection fee (approx. EUR 5,000) applies; this is difficult to generalise and was therefore disregarded in the analysis due to its limited significance.
[3] No additional investment is expected, as gas boilers are already implemented and operational on site. The installation of additional gas boilers does not align of the city´s climate neutrality goals.
[4] VDI - Verein Deutscher Ingenieure (Association of German Engineers)

District heating from Stadtwerke Leipzig is subject to the EU ETS[5] (European Union Emissions Trading System). Accordingly, an average CO_2 price of EUR 69.19/t CO_2 for the past year (2024) was applied and evaluated using the stated emissions factor of 0.159 t/MWh. As a result, emissions costs account for around 6% of total costs and are currently negligible.

In the case of the natural gas boiler, it quickly becomes clear that continued operation of the existing system is by far the most economical solution. For operating costs, an efficiency of 85% and a natural gas price of EUR 70/MWh were assumed. The considerations regarding the CO_2 price and its development are analogous to district heating, although it should be noted that the emissions factor for natural gas, at 0.200 t/MWh, is higher than that of district heating. At the same time, the price per tonne of CO_2 under the BEHG [6]is around EUR 15 lower than under the EU ETS, thereby offsetting the higher emissions factor.

Under the current CO_2 regime, it is difficult to imagine CO_2 prices rising to a level that would enable cost parity with the municipal heat storage system. Consequently, there is a high need for subsidies to convince residents to participate in the municipal heat storage solution. First, CAPEX funding of 50–60% is needed to reduce initial capital expenditures. Additional subsidies are required for ongoing operations to accommodate the relatively complex billing model. If, as the project progresses, waste heat can be integrated into the system at low or no cost, this should be reflected in reduced operational subsidies or potentially the elimination of subsidies altogether. However, to launch the project, sufficient financial resources and an appropriate subsidy framework are essential to enable its initiation.

[5] EU ETS (European Union Emissions Trading System) The EU Emissions Trading System (EU ETS) is a cap-and-trade program that sets limits on greenhouse gas emissions from major EU industries. Companies receive or buy allowances and can trade them, encouraging emission reductions and supporting the EU's climate goals.

[6] BEHG (Bundes-Emissionshandelsgesetz), is the Federal Emissions Trading Act in Germany.
It regulates the national emissions trading system for fuels and certain sectors not covered by the EU ETS, aiming to reduce greenhouse gas emissions by putting a price on CO_2 emissions from heating fuels and transport fuels within Germany.

8. CONCLUSION AND OUTLOOK

The planned municipal heat storage system in Leipzig-Plagwitz represents a forward-looking and technically robust approach to sustainable urban energy supply. By utilising Borehole Thermal Energy Storage (BTES) in combination with decentralised heat pumps and a shared prosumer-based infrastructure, the project demonstrates that low-carbon, community-oriented heating solutions are both technically achievable and scalable—even in densely built urban districts and heritage-protected environments. The concept provides an innovative alternative to conventional heating systems and aligns with Leipzig's ambition to achieve climate neutrality by 2040, while also contributing to broader European decarbonisation strategies.

The legal and organisational analysis shows that the system's bidirectional nature does not fit neatly into existing district heating regulations, highlighting a regulatory gap that must be addressed. At the same time, water and road law requirements are well defined and manageable through established permitting procedures. The proposed hybrid contract model—based on usage, feed-in, and supply agreements—creates a flexible framework that enables participation from private, commercial, and institutional actors, thereby reinforcing the collaborative character of the project.

From an economic perspective, the concept faces challenges due to its high upfront investment costs. While geothermal systems offer low and stable operating costs, capital expenditures remain substantial, making adequate public funding indispensable. The integration of waste heat, renewable electricity, and optimised system design will further enhance long-term economic viability and resilience.

Looking ahead, the project has the potential to serve as a model for many European cities seeking climate-friendly heating solutions that work within spatial, regulatory, or heritage constraints. Its modular design allows for incremental expansion and adaptation, while the prosumer-based structure fosters local engagement and creates new opportunities for cooperative energy ecosystems. Continued collaboration between the city, scientific partners, and private stakeholders will be crucial to ensure regulatory clarity, optimise system performance, and establish a viable funding framework.

Although not foreseen within the MonuPED project timeframe, if successfully implemented, the Leipzig-Plagwitz heat storage system could become a flagship initiative for sustainable urban energy infrastructure - demonstrating how innovative thermal storage, shared use models, and community engagement can accelerate the transition to climate-neutral cities.