sciendo ACC JOURNAL 2025, 31(1) DOI: 10.2478/acc-2025-0004

Development of an Integrated Software Workflow for District Heating Network Planning: A Structured Methodological Approach

Jonas Pfeiffer[1]; **Matthias Kunick**[2]

Zittau/Görlitz University of Applied Sciences, Faculty of Mechanical Engineering,
Department of Energy Systems Technology,
Schwenninger Weg 1, 02763, Zittau, Germany

e-mail: [1]jonas.pfeiffer@hszg.de; [2]m.kunick@hszg.de

Abstract

This article outlines the process of streamlining existing methods for conceptualizing and planning district heating networks (DHNs) by designing an integrated workflow. Existing solutions are often fragmented or lack accessibility and transparency. In this article, an integrated methodological approach combines Geographic Information System (GIS) supported spatial analysis of heat demands and potentials, generation and simulation of heating networks, and heat generator dimensioning within a unified workflow. The methodology is validated through case studies and aims to enable transparent and reproducible planning of sustainable heating networks. The developed approaches are the result of a preliminary research project funded by the Saxon State Ministry of Science, Culture and Tourism (SMWK) and they are implemented in the open-source software DistrictHeatingSim, which is publicly available on GitHub.

Keywords

District heating; Heat-supply; GIS; Optimization; Simulation; Pandapipes.

Introduction

The transition to renewable energy sources in heat supply systems is essential for reducing dependence on fossil fuels and achieving climate targets. DHNs are a key element in this transition, as they integrate diverse renewable heat sources, such as industrial waste heat, surface water heat, and large-scale solar thermal energy, with seasonal storage. By utilizing centralized heat production and distribution, district heating enables the economic and renewable heat supply in densely built urban areas by using various renewable energy sources that are not feasible for individual buildings, especially in city centers (Höffner & Glombik, 2024). Additionally, combined heat and power (CHP) systems integrated into DHNs offer higher efficiency, reducing CO_2 emissions and primary energy consumption (Gonzalez-Castellanos et al., 2018). However, planning and optimizing these networks remains a complex challenge that requires the integration of multiple disciplines, including technical, economic, and spatial analyses.

A well-designed DHN must be adaptable to local conditions while ensuring cost-effectiveness and reliability. The planning process involves determining optimal pipe routes, dimensioning generation and storage units and evaluating the economic feasibility of different system configurations. Spatial constraints, fluctuating heat demands, and potential and regulatory

© 2025 Author(s). This work is distributed under the Creative Commons Attribution-4.0 license (https://creativecommons.org/licenses/by-nc/4.0/).

requirements further complicate the decision-making process. In this process, advanced computational methods, including thermo-hydraulic simulations and optimization models, are used. (Banze & Kneiske, 2024)

Existing solutions typically focus on specific aspects, such as network hydraulics, GIS-based demand mapping, or techno-economic assessments, but fail to provide an integrated workflow that supports all stages of the planning process. Many proprietary tools limit transparency due to their closed-source nature, restricting their use in research or concise planning (Hilpert et al., 2018; Howells et al., 2011). For many specific tasks, adequate open-source software solutions are available (Lohmeier et al., 2020; Panitz et al., 2022). However, those often lack desired functionalities, a generic data format compatible with other tools, and/or a graphical user interface for the end user.

This article documents the development of the open-source software DistrictHeatingSim for DHN planning that addresses these challenges. The article begins with an introduction to the importance of DHNs in the transition to renewable energy and the complexities involved in their planning. It then reviews existing software solutions, highlighting their limitations and the need for an integrated approach. The methodology section outlines the data integration and processing steps, including GIS-based spatial analysis and heat demand calculation. It also details graph-based algorithms for network generation and thermo-hydraulic simulations for network dimensioning. The techno-economic evaluation section discusses the cost assessment of different network configurations, ensuring economic feasibility. Finally, the results and discussion sections present a case study in Bad Muskau, validating the software's effectiveness and discussing its strengths and areas for improvement. This comprehensive approach aims to establish a standardized process for comparable results, reducing the time and effort required for planning while enhancing the comparison of different variants. It ultimately supports the development of sustainable and efficient DHNs and contributes to the broader goal of decarbonizing urban energy systems.

1 Literature Review

1.1 Scientific Approaches to District Heating Planning

District heating planning has seen significant advancements, with research focusing on network optimization, load modeling, and the optimization of heat generator operation. In a comprehensive study, Höffner & Glombik (2024) evaluated various energy system planning tools, particularly their applicability to urban energy systems and district heating. Their analysis highlighted the predominance of open-source tools utilizing Python or Modelica libraries, which can support various tasks across different planning phases. However, they identified a notable gap in multi-energy system planning in renewable energy integration.

For network modeling and optimization, Banze & Kneiske (2024) introduced the DAVE tool, a Python-based data fusion framework designed to automate the generation of customized energy network models. By leveraging open datasets, DAVE addresses the challenge of restricted access to real network data, which is often classified as critical infrastructure. The tool currently facilitates the creation of GIS-based power and gas networks compatible with standard simulation software, with plans to extend its capabilities to DHNs.

Vieth et al. (2025) present a comprehensive co-planning approach for DHNs that integrates operational considerations and techno-economic optimization. Their method uses real GIS data, a surrogate optimization algorithm, and dynamic simulations in Modelica. Similarly, Fuchs & Müller (2017) propose an automated model generation framework based on OpenStreetMap (2025), offering static and dynamic simulation capabilities. Both approaches provide technically detailed solutions and aim to enhance the accuracy of DHN planning models.

However, these methods are largely optimization-driven and rely on high input detail and specificity, which may not be available during early planning phases. For example, Vieth et al. (2025) apply heat demand data from a heat cadastre top-down to generate a parameterized simulation model. Based on this model, total system costs are calculated using predefined cost functions. While this provides valuable theoretical insights, it is often impractical in real-world planning contexts, especially because segment-specific cost data for DHNs (e.g., pipe installation costs by street segment) are typically unavailable at early stages or vary significantly depending on local conditions.

Wirtz et al. (2020) proposed a mathematical optimization approach for fifth-generation district heating systems. Their methodology emphasizes incorporating renewable energy sources and decentralized storage units to enhance operational efficiency and sustainability. Gonzalez-Castellanos et al. (2018) addressed the complexities of network-constrained CHP unit commitment. They developed strategies to optimize heat and power generation in response to dynamic network conditions, thereby improving the flexibility and reliability of CHP systems within DHNs. Panitz et al. (2022) explored software-supported investment optimization for DHNs using Mixed Integer Linear Programming from an economic and infrastructural perspective. Sollich et al. (2025) investigated pathways for decarbonizing existing DHNs through optimal retrofitting of production units. Their findings offer actionable insights into transforming traditional district heating systems into low-carbon energy solutions.

Sporleder et al. (2022) provide a broader perspective. They conducted a systematic review of optimization methods in district heating system design. Their analysis underscores the importance of integrating low-temperature heat sources, thermal storage solutions, and energy conversion technologies such as geothermal energy and large-scale heat pumps. Further elaboration on these topics is found in Sporleder's dissertation (Sporleder, 2024), which delves into developing tools to optimize district heating system design.

Another essential aspect of DHN simulation is load modeling. Common approaches include using Verein Deutscher Ingenieure (VDI, 2025) standard load profiles and load profiles for gas-based heating demand estimation (BDEW, 2024). Additionally, researchers such as Lombardi et al. (2019), Fischer et al. (2016), Büttner et al. (2022), and Kumpf (2016) have contributed to advanced demand forecasting techniques. However, these models need detailed usage behavior data, which is often unavailable.

These investigations demonstrate efforts to enhance district heating planning by employing interdisciplinary methodologies. By integrating geospatial analysis, thermo-hydraulic simulations, and techno-economic evaluations, researchers develop holistic frameworks for modern energy systems. Nevertheless, the absence of standardized protocols underscores the necessity for a systematic methodology.

1.2 Existing Software Solutions and Tools for District Heating Networks

Various proprietary and open-source software solutions have been developed for DHN planning, each addressing specific network simulation, optimization, or economic evaluation aspects. These tools can be broadly categorized into proprietary commercial and open-source modeling tools and frameworks.

1.2.1 Proprietary Software Solutions

STANET (2016) is traditionally widely used for thermo-hydraulic network calculations, while EBSILON (Iqony EBSILON, 2025) is used for energy system calculations. While both are robust calculation tools, they do not excel in integrated district heating planning. More recent software, like nPro (Wirtz, 2023) and VICUS Districts (VICUS Software, 2025), offer integrated spatial analysis, producer retrofitting and cost calculations. However, nPro lacks transient thermo-hydraulic calculation. VICUS Districts are restricted in delivering an integrated workflow and are more focused on thermo-hydraulic calculation of net and producers and 5th-generation low-temperature DHNs. Also notable are TOP-Energy (2025) and Edgar Energy (Edgar, 2025), proprietary energy system calculation software tools not specialized in district heating planning.

1.2.2 Open-Source Software Solutions

The push for open science and reproducible modeling has led to the development of several open-source tools, although most remain fragmented and do not provide an integrated workflow. Pandapipes (Lohmeier et al., 2020) is an open-source Python library for thermo-hydraulic simulations and delivers a node-based framework for heating network generation and calculation. Scenocalc Fernwärme 2.0 (Solites, 2017) and GHEtool (Peere & Blanke, 2022) offer specialized calculations for solar thermal and geothermal systems, respectively, but are not integrated with district heating planning. The Python software flixOpt (Panitz et al., 2022) enables investment and operational optimization yet is quite complex and requires extensive domain knowledge. EnSySim (Herling et al., 2022), developed in a previous project at HSZG, applies stochastic demand modeling for cellular energy systems. Sophena (GreenDelta, 2025) is an open-source planning tool for district heating with a UI and a database with producers and time-dependent calculations. However, it lacks GIS-based calculations, thermo-hydraulic calculations, and proper results. Additional open-source energy system modeling software such as City Energy Analyst (Fonseca, et al., 2025), oemof (Hilpert et al., 2018), EnergyPLAN (Lund et al., 2021), OSeMOSYS (Howells et al., 2011) provide various functionalities but lack interoperability and require extensive training for efficient usage.

1.2.3 Data Sources Available

Data availability is another critical factor influencing district heating planning. Various public datasets, including the Geothermal Atlas (Sachsen, 2025), PVGIS (EU Science Hub, 2025), Solarkataster (SAENA, 2025), and the new waste heat database (BAFA, 2025) provide valuable inputs for assessing renewable energy potential. Meteorological data from (DWD, 2025) further enhances the accuracy of simulation models by incorporating weather-dependent variations in heat demand.

1.3 Addressing the Need for an Integrated Methodology

Despite the availability of various tools, there is a notable absence of a unified solution that seamlessly integrates GIS-based network modeling, thermo-hydraulic simulation, and techno-economic evaluation. This fragmentation leads to limited interoperability and inflexible workflows, posing significant challenges in current research and practical applications.

Table 1 shows the main gaps identified in existing district heating planning tools and outlines how this work proposes to bridge these gaps.

Tab. 1: *Identified challenges and solution approaches in the integrated methodology for district heating networks*

Challenges identified	Proposed solution
Limited interoperability Existing open-source tools often focus on specific aspects, such as thermo-hydraulics or optimization, without offering an integrated workflow.	**Modular integration** Development of a modular framework that combines GIS-based spatial analysis, thermo-hydraulic simulation, and techno-economic evaluation into a cohesive workflow.
Restricted accessibility of proprietary software High costs and closed-source models limit the use of proprietary software in academic research and municipal energy planning.	**Open-source accessibility** Creation of a transparent, open-source framework that is freely accessible, promoting collaborative development and widespread adoption.
Lack of user-friendly and interactive solutions Many energy-modeling tools require extensive programming knowledge, making them less accessible to planners and decision-makers.	**User-friendly interfaces** Incorporation of visualization tools and interactive elements, enabling users to explore and optimize various district heating configurations without the need for advanced programming skills.

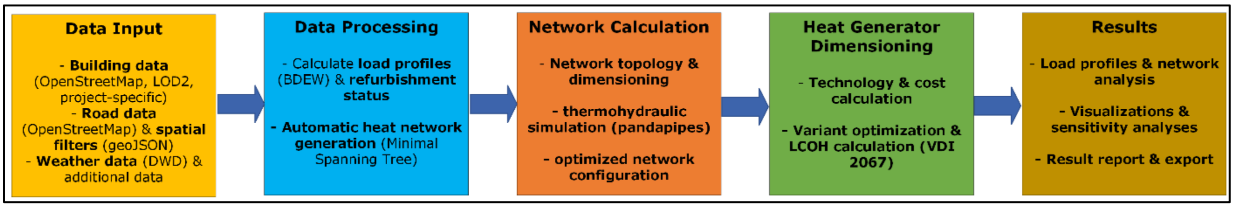
Source: Own

Table 1 highlights significant challenges. While these listed challenges are paramount, calculation algorithms and data processing steps are also critical. The proposed framework aims to directly address these challenges and provide a flexible, scalable, and transparent solution for sustainable DHN planning. This approach not only enhances reproducibility and accessibility but also empowers planners and decision-makers with intuitive tools to facilitate informed energy planning. It is important to note that this work does not aim to develop new optimization methods. Instead, it focuses on streamlining DHN generation, thermos-hydraulic simulation, and heat generation planning by integrating openly available data with project-specific data using automated, reproducible workflows.

2 Methodology

2.1 Data Integration and Processing

The proposed framework integrates multiple data sources and processing steps to enable a structured and transparent DHN planning workflow. As shown in Figure 1, a structured stepwise workflow is established to handle data acquisition, preprocessing, network modeling, and evaluation.



Source: Own

Fig. 1: *Overview of data sources and integration workflow*

The workflow was developed by reviewing previous projects, including one at the Zittau/Görlitz University of Applied Science in Görlitz. The methodology is illustrated using data from this project. Critical data (heat demand in Figure 2) is anonymized.

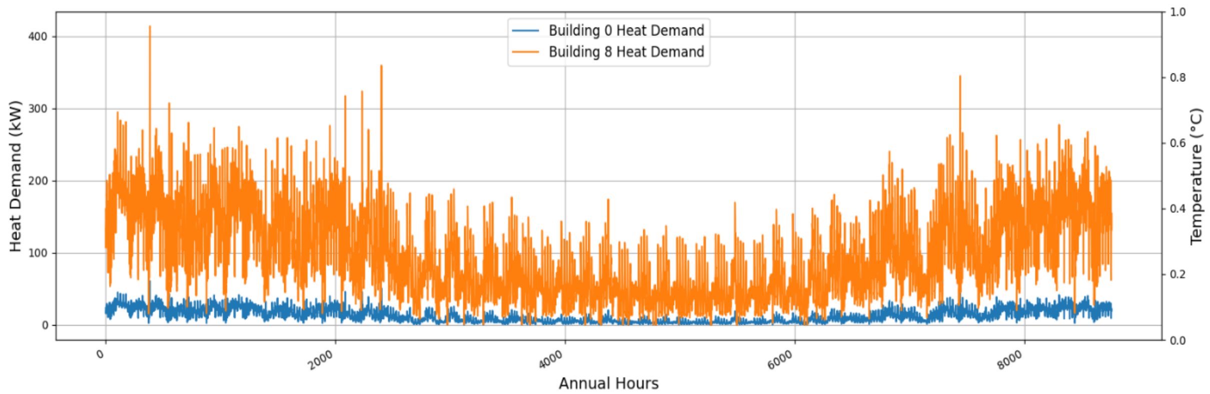
2.2 Data Acquisition and Preprocessing

A structured and consistent data acquisition process is essential for developing an accurate DHN model. The methodology integrates geospatial, infrastructure, and demand-related datasets for reliable network generation and simulation.

The first step in data acquisition involves identifying the buildings that will be part of the DHN. This is achieved by collecting building addresses, which are then geocoded using external services such as Nominatim (Hoffmann, 2025). The geocoding process converts addresses into precise latitude and longitude coordinates, ensuring that each building is accurately placed within the spatial model. Once the project area is defined, relevant geospatial data is retrieved from OpenStreetMap (2025). The two primary data sources include street networks, which provide the basis for pipe routing and building footprints, which define the heat demand distribution and network connection points. All spatial information is automatically converted to a unified coordinate reference system to maintain consistency across datasets. The methodology employs ETRS89 (ETRS89, 2008), ensuring high positional accuracy and compatibility with other geographic datasets.

For a reliable network simulation, heat demand data is required for each building. The most straightforward approach uses existing energy consumption data (e.g., gas, oil, electricity), which is often available for a given project area. This data directly estimates heat demand, simplifying the transition to district heating. The methodology incorporates BDEW standard gas consumption load profiles (BDEW, 2024) to further refine demand modeling. These profiles categorize different building types (e.g., residential, commercial, industrial) and generate time-dependent heat demand curves. This time-series heat demand data is crucial for dynamic simulations of the DHN, allowing for realistic load variations throughout the year.

Two examples of calculated heat demand curves with different building types and total heat demands are shown in Figure 2. Building 0 has a total heat demand of 108,000 kWh and is categorized as “GBD” (“other services”) by definition. Building 8 has a total heat demand of 825,000 kWh and is categorized as “HMF” (“apartment building”) by definition.



Source: Own, plotted in DistrictHeatingSim

Fig. 2: *Building load profiles*

This preprocessing step integrates automated geocoding, GIS processing, and standardized heat demand calculation to ensure a well-structured, accurate, and computationally efficient foundation for the subsequent network generation and simulation phases.

2.3 Network Generation Using Graph-Based Optimization Algorithms

The generation of DHNs in this work is not aimed at finding an optimal or cost-minimal layout in a strict mathematical sense. Instead, the goal is to automatically generate spatially plausible network structures that follow existing road geometries and realistically connect relevant buildings. This allows for a fast and reproducible estimation of pipe lengths, which serves as a basis for subsequent thermo-hydraulic simulation and cost analysis. The proposed method leverages OpenStreetMap street data and building locations to identify feasible pipe routing paths. Since buildings are often set back from the road, each is first connected to the nearest point on the street network to ensure physically plausible pipe entry points.

To construct the network structure, a Minimum Spanning Tree (MST) algorithm is used as a baseline to ensure that all connections are covered with minimal total length. However, the MST is not used as a final network or interpreted as an optimized solution. Instead, it provides a simple and computationally efficient approximation of a connected network. In a post-processing step, the resulting tree is adjusted to better align with the actual street layout using street points as additional nodes for a more detailed MST. This ensures that the resulting pipe segments are technically feasible and suited for further hydraulic modeling using tools like pandapipes (Lohmeier et al., 2020). This approach reduces the modeling effort while maintaining sufficient realism for early-stage cost and performance estimation. Examples of the initial and adjusted network layouts are shown in Figures 3 and 4 respectively.

Source: Own, plotted in DistrictHeatingSim

Fig. 3: *Automatically generated network structure on the example in Görlitz*

Source: Own, plotted in DistrictHeatingSim

Fig. 4: *Post-processed generated network structure on the example in Görlitz*

Despite algorithmic generation, final adjustments may be required based on specific project constraints. The methodology integrates interactive refinement capabilities through a Leaflet.js-based interface (Agafonkin, 2025) embedded in the PyQt5-GUI (Python GUIs, 2025). Users can visualize, modify, and validate the generated network within an HTML-based interactive environment. Additionally, the network can be exported in GeoJSON format (GeoJSON, 2016) for external modifications in other GIS software like QGIS, allowing planners to fine-tune the layout based on site-specific requirements. This combined automated and interactive approach balances computational efficiency and practical adaptability, enabling planners to generate and refine DHNs in a structured workflow quickly.

2.4 Thermo-Hydraulic Simulation and Dimensioning of Supply Systems

The thermo-hydraulic simulation of DHNs is crucial in ensuring efficient and reliable heat distribution. The developed methodology leverages the pandapipes framework to model and analyze network performance under various operating conditions. The simulation involves several key computations like pressure drop calculations across the pipe network to assess hydraulic feasibility and identify potential bottlenecks or temperature distribution analysis, ensuring supply temperatures remain within acceptable limits throughout the network. These calculations allow for a network design that minimizes thermal losses while maintaining operational efficiency.

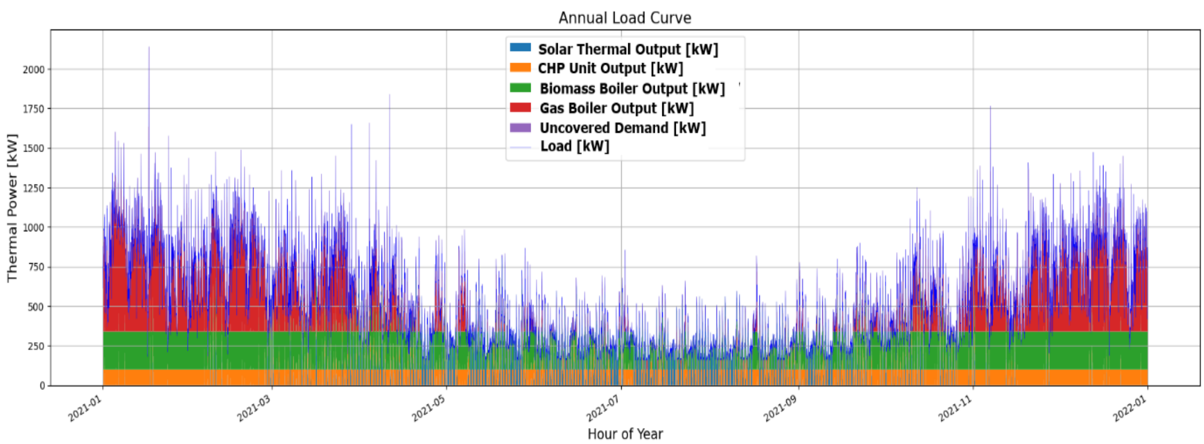
Beyond the core pandapipes capabilities, additional functionalities have been integrated to enhance the simulation process. A direct import of GeoJSON files to a pandapipes net was established for fast data processing, allowing seamless integration of network layouts generated in previous processing steps. Advanced control algorithms to improve system stability under fluctuating load conditions were designed for net calculation with pandapipes. A low-temperature network implementation, including decentralized heat pump integration, was developed to evaluate alternative supply strategies and enhance energy efficiency. These enhancements ensure the simulation framework is adaptable to various district heating configurations. The thermo-hydraulic simulations generate important outputs such as dimensioned pipe networks and calculated heat losses, providing insights into thermal performance and energy efficiency. Further time-series results for supply and demand, allowing for dynamic analysis of network behavior over different operational scenarios, are saved.

During development, extensive testing of pandapipes was conducted to validate model accuracy and identify potential improvements. Issues encountered during simulations were reported back to the pandapipes developers, who contributed to refining the framework and ensuring its robustness.

2.5 Techno-Economic Evaluation

A hierarchical approach is applied to model heat generators and simulate the operation of the energy system, balancing computational efficiency with flexibility. This methodology allows for assessing various configurations, including CHP units, heat pumps, solar thermal collectors, geothermal probes, waste heat, and conventional boilers. Simulations are conducted for an entire year to capture the fluctuations in heat demand and supply, accounting for external factors such as ambient temperature and solar availability. For the resulting load profile, the contributions of all heat generators are accumulated according to their control strategies. More complex control strategies combined with seasonal thermal energy storage are currently under development.

Figure 5 shows an example of a simulated load profile and how the hierarchical control strategy meets the demand at each time interval throughout the year.



Source: Own, plotted in DistrictHeatingSim

Fig. 5: *Load Simulation of Heat Generation*

The levelized cost of heat is calculated according to the VDI 2067 (VDI, 2025) methodology to enable a standardized cost comparison. This metric provides insights into the overall cost-effectiveness of each configuration by considering lifetime energy production, investment amortization, and operational costs. Publicly available cost databases such as (KEA-BW Klimaschutz- und Energieagentur Baden-Württemberg GmbH, 2024) and real-world project data are used to ensure realistic input parameters. The simulation results are presented through interactive dashboards, allowing for scenario-based comparisons of different network configurations. These dashboards visualize key performance indicators such as total investment, annual operational costs, system efficiency, and CO_2 savings. Stakeholders can explore multiple planning options, adjust parameters dynamically, and identify the most cost-effective and sustainable solutions. This approach does not aim to find a mathematical optimum but instead prioritizes flexibility and transparency for stakeholders in exploring planning options.

3 Results

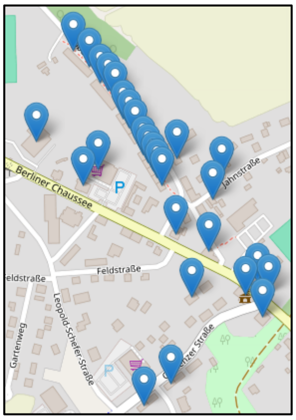
A case study was conducted using real-world data from a district in Bad Muskau, a German city located in Saxony at the Neisse River, where conceptualization of heat distribution options is currently being evaluated in a project between the Zittau/Görlitz University of Applied Sciences and the Ver- und Entsorgungswerke Bad Muskau GmbH (VEWBM, local energy supplier) to validate the developed Software methodology for fast variant generation. The local specifics regarding the study area and data sources are described in Table 2.

Tab. 2: *Bad Muskau's case study specifics*

Geographical scope	The case study covers an urban area with mixed residential, commercial, and public buildings.
Heat demand data	VEWBM supplies all buildings with gas, providing access to annual demand data. A GIS-based analysis incorporating OpenStreetMap data was utilized to estimate the spatial distribution of heating demand.
Heating network infrastructure	There is no existing heating infrastructure in place.
Renewable energy potential	The feasibility of integrating local biomass, profound geothermal energy, and water thermal energy from the Neisse River was examined. Due to space constraints, large-scale solar thermal energy is not feasible, and waste heat sources are unavailable.
Special features	Bad Muskau is part of the UNESCO World Heritage site "Muskauer Park / Park Mużakowski" which presents challenges for establishing heat generation sites due to preservation.

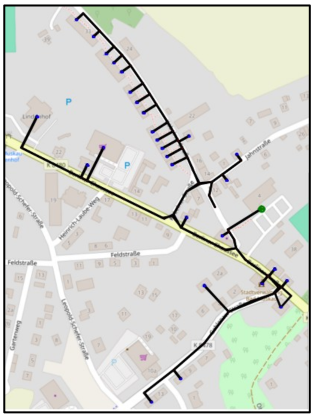
Source: Own

The Methodology outlines that the first step involves collecting the buildings in the considered area. VEWBM provided the buildings, corresponding addresses, and their gas usage for heating and warm water. Figure 6 shows the geocoded addresses. For an initial calculation, the location of a single heat generator was chosen to be at an old supermarket site. The resulting network is shown in Figure 7.



Source: Case study Bad Muskau, plotted in DistrictHeatingSim

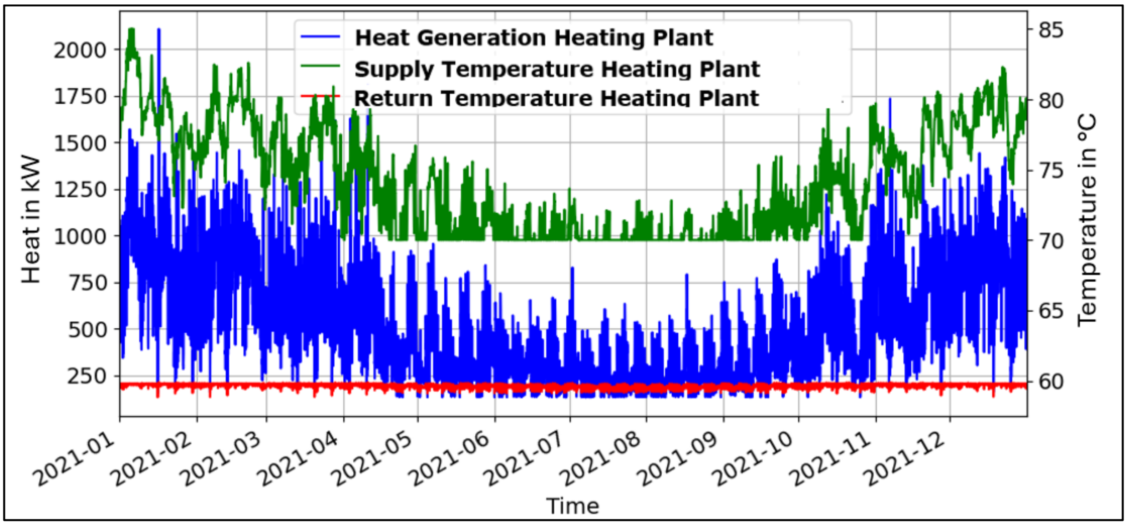
Fig. 6: *Building positions*



Source: Case study Bad Muskau, plotted in DistrictHeatingSim

Fig. 7: *Generated net structure*

A network configuration simulation was conducted with the network generated, providing data on pressure losses across different pipe diameters, temperature profiles, and heat losses along the network. Figure 8 shows the results from the time series calculation within DistrictHeatingSim. The results for the heat generation (heat input in the network), supply temperature, and return temperature are plotted. The supply temperature is calculated using a linear control strategy based on the air temperature from the weather data. In this case, the return temperature is 60 °C for the heat consumers and, therefore, lower at the central return point.



Source: Own, plotted in DistrictHeatingSim

Fig. 8: *Results of thermo-hydraulic net simulation of Bad Muskau*

Based on the calculation results, investment and operational costs were evaluated for different scenarios using VDI 2067 (VDI, 2025) cost models. The scenarios were modeled as shown in the example in Figure 5. With generators dimensioned and heat production calculated, the levelized heat cost was calculated for these multiple configurations. Furthermore, sensitivity analyses assessed the impact of energy price fluctuations and infrastructure costs. The tool was also used to generate different visualizations for the project. Several results can be extracted, but final data is not yet available since the project is ongoing. The developed codebase is available on GitHub as DistrictHeatingSim (Pfeiffer, 2025).

4 Discussion

The georeferencing of heat demand data during preprocessing, combined with the automatic generation of GIS data in the GeoJSON format, enables the rapid creation of a thermo-hydraulic model. Configuration options allow the generation of multiple variants based on input data, which then can be effectively stored. Utilizing the comprehensive framework built around pandapipes, efficient network and time-series calculations are achievable, supporting various network configurations such as decentralized heat pump cold nets and multiple producer locations. The network calculations yield critical key performance indicators, including heat loss and power consumption of circulation pumps.

Following these calculations, the dimensioning of heat generators can be performed using extensive calculation options. Cost calculations for pipes and heat exchangers can be directly derived from the GIS data, assuming cost per meter for pipes and per kilowatt for heat exchangers (installation costs included). Various calculation options are available for generators and optimization processes. The software supports the generation of multiple plots to export the most important information.

The software also supports renewable energy integration by enabling scenario analysis for incorporating waste heat, solar thermal, and heat pumps (using geothermal or aqua thermal heat). This feature is crucial for simulating low-carbon energy systems. Another key strength of the methodology is that it promotes transparent decision-making by providing precise and reproducible results. Planners and policymakers can engage in informed discussions through interactive visualization tools, leading to more effective and inclusive energy planning processes. Another important feature of the developed software is serialization, which enables users to save their work on the file system and load it into the software once they want to continue their work.

The findings align with previous research highlighting the importance of integrated approaches in DHN planning. For instance, Höffner & Glombik (2024) emphasized the need for transparent and reproducible planning processes, a core principle of our developed methodology. Similarly, Banze & Kneiske (2024) demonstrated the benefits of automating network generation using GIS data, a feature central to our framework. While the current work has streamlined and accelerated processes by integrating existing algorithms, which have been effective for steps previously done manually or with various tools, including Excel, it is important to note that the focus was not on optimizing individual calculation steps. Therefore, further comparisons with existing algorithms are not meaningful at this point.

Currently, the computational complexity is limited to smaller DHNs. Large-scale DHNs require significant computational resources, particularly for time-series simulations and optimization models. Ensuring a balance between computational efficiency and model accuracy remains challenging, especially when dealing with high-resolution thermo-hydraulic calculations with pandapipes. The implementation performs slowly for more extensive networks due to inefficiencies in the additional control algorithms integrated into the pandapipes calculation. Some have already been replaced within pandapipes through development going forward. Further improvements in algorithmic efficiency and parallel computing techniques could help address this issue in DistrictHeatingSim. User accessibility is another area for improvement. However, future development should focus on user-friendly interfaces and automated workflows to support non-expert users, making the tool more accessible to a broader audience, including municipal planners and smaller energy providers.

Conclusion

This article presents an integrated methodology for DHN planning that combines GIS-supported spatial analysis, thermo-hydraulic simulations, and techno-economic assessments into a cohesive open-source framework. The developed approach provides a comprehensive and adaptable planning tool. Its modular design ensures flexibility, allowing for region-specific adaptations in the future while supporting the integration of renewable energy sources in district heating systems. By fostering transparency and reproducibility, the framework promotes collaboration and broader adoption, bridging spatial analysis, network modeling, and cost assessment to streamline the planning process. Furthermore, it enhances decision-making for urban planners by providing evidence-based scenario analysis and supporting long-term energy transition strategies.

While the methodology demonstrates significant potential, several areas for further research and development remain. Refining network generation algorithms by incorporating a Steiner tree modeling approach, machine learning, or other heuristic methods could improve network layout generation based on multiple variables. The current algorithm cannot generate meshed networks, which would help optimize net hydraulics. Expanding case study applications across more projects with different boundary conditions will help validate the software's adaptability and effectiveness. Additionally, improvements in automation and user-friendliness, such as intuitive graphical interfaces and real-time data integration, would make the tool more accessible to non-expert users. Further integration with multi-energy systems, including electricity, seasonal storage, and demand response mechanisms, could extend the framework's applicability, particularly in hybrid heating solutions that combine district heating with decentralized technologies. More precise benchmarks must be established for future work to assess process efficiency and enable qualitative and quantitative comparisons with other software tools.

The methodology and software DistrictHeatingSim form a basis for future district heating system research. In the short term, efforts will focus on validating methods and improving data and error handling in the workflow. Long-term goals include optimizing urban energy systems and considering heat, gas, electricity, and buildings. This framework aims to enable sustainable and efficient urban heating systems, contributing to transparent and flexible district heating planning and supporting the move towards decarbonized urban energy infrastructures. The software is available on GitHub for contributions, further information, and documentation (Pfeiffer, 2025).

Acknowledgements

The Saxon State Ministry for Science, Culture, and Tourism (SMWK) funded this research through project funding TG70-HAW SMWK-NEUES, titled "Development and testing of methods and tools for designing sustainable heating networks".

We also thank Ver- und Entsorgungswerke Bad Muskau GmbH and all stakeholders in Bad Muskau for their assistance during the ongoing project and for providing data.

References

Agafonkin, V. (2025). *Leaflet – an open-source JavaScript library for mobile-friendly interactive maps*. https://leafletjs.com/

Banze, T., & Kneiske, T. M. (2024). Open data for energy networks: introducing DAVE—a data fusion tool for automated network generation. *Scientific Reports*, *14*. https://doi.org/10.1038/s41598-024-52199-w

BAFA. (2025). *Plattform für Abwärme*. Bundesamt für Wirtschaft und Ausfuhrkontrolle. https://www.bfee-online.de/BfEE/DE/Effizienzpolitik/Plattform_fuer_Abwaerme/plattform_fuer_abwaerme_node.html

BDEW. (2024). *BDEW/VKU/GEODE-Leitfaden Abwicklung von Standardlastprofilen Gas*. Bundesverband der Energie- und Wasserwirtschaft e. V. https://www.bdew.de/media/documents/20240322_LF_SLP_Gas_KoV_XIV_final_clean.pdf

Büttner, C., Amme, J., Endres, J., Malla, A., Schachler, B., & Cußmann, I. (2022). Open modeling of electricity and heat demand curves for all residential buildings in Germany. *Energy Informatics*, *5*(Suppl 1). https://doi.org/10.1186/s42162-022-00201-y

DWD. (2025). *Testreferenzjahre (TRY)*. Deutscher Wetterdienst. https://www.dwd.de/DE/leistungen/testreferenzjahre/testreferenzjahre.html

Edgar. (2025). *Schnell zukunftsfähige Energiesysteme planen und optimieren*. FI Freiberg Institut für Energie- und Klimaökonomie GmbH. https://go-edgar.de/

ETRS89. (2008). *European Terrestrial Reference System 89*. https://web.archive.org/web/20090307095956/http://etrs89.ensg.ign.fr/en/

EU Science Hub. (2025). *Photovoltaic Geographical Information System (PVGIS)*. The Joint Research Centre: EU Science Hub. https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis_en

Fischer, D., Wolf, T., Scherer, J., & Wille-Haussmann, B. (2016). A stochastic bottom-up model for space heating and domestic hot water load profiles for German households. *Energy and Buildings*, *124*, 120–128. https://doi.org/10.1016/j.enbuild.2016.04.069

Fonseca, J. et al. (2025). *CityEnergyAnalyst v3.39.2*. [Computer software]. Zenodo. https://doi.org/10.5281/zenodo.14617664

Fuchs, M., & Müller, D. (2017). Automated Design and Model Generation for a District Heating Network from OpenStreetMap Data. In *Proceedings of Building Simulation 2017: 15th Conference of IBPSA*. (pp. 2050–2059) https://doi.org/10.26868/25222708.2017.562

GeoJSON. (2016). *GeoJSON*. https://geojson.org/

Gonzalez-Castellanos, A., Thakurta, P. G., & Bischi, A. (2018). Flexible unit commitment of a network-constrained combined heat and power system. *arXiv preprint*. https://doi.org/10.48550/arXiv.1809.09508

GreenDelta. (2025). *Sophena*. [Computer software]. GreenDelta GmbH. https://github.com/GreenDelta/Sophena/

Herling, M., Kittan, T., Goikoetxea, I., & Kratzsch, A. (2022). *EnSySim – THERESAnext: Simulationsumgebung zur Entwicklung Intelligenter Betriebsalgorithmen für Sektorkoppelnde Speicher*. IPM. https://ipm.hszg.de/fileadmin/NEU/Redaktion-IPM/Dokumente/Poster/MTPA_202210_TheresaNext_EnSySim.pdf

Hilpert, S., Kaldemeyer, C., Krien, U., Günther, S., Wingenbach, C., & Plessmann, G. (2018). The Open Energy Modelling Framework (oemof) - A new approach to facilitate open science in energy system modelling. *Energy Strategy Reviews*, *22*, 16–25. https://doi.org/10.1016/j.esr.2018.07.001

Hoffmann, S. (2025). *Nominatim: Open Source search based on OpenStreetMap data*. [Computer software]. https://github.com/osm-search/Nominatim/

Höffner, D., & Glombik, S. (2024). Energy system planning and analysis software—A comprehensive meta-review with special attention to urban energy systems and district heating. *Energy*, *307*. https://doi.org/10.1016/j.energy.2024.132542

Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., Hughes, A., Silveira, S., DeCarolis, J., Bazillian, M., & Roehrl, A. (2011). OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. *Energy Policy*, *39*(10), 5850–5870. https://doi.org/10.1016/j.enpol.2011.06.033

Iqony EBSILON. (2025). *EBSILON® Professional*. Iqony Solutions GmbH. https://www.ebsilon.com/de/

KEA-BW. (2024). *Unterlagen zu Vergabe und Betrieb sowie Technikkatalog*. KEA-BW Klimaschutz- und Energieagentur Baden-Württemberg GmbH. https://www.kea-bw.de/waermewende/angebote/downloads

Kumpf, L. (2016). *Entwicklung von Referenzlastprofilen für Schulen und Kitas anhand von Realdaten*. [Masterarbeit, Technische Universität Darmstadt]. https://energiemanagement.stadt-frankfurt.de/Service/Dokumente/Entwicklung-von-Referenzlastprofilen-fuer-Schulen-und-Kitas.pdf

Lohmeier, D., Cronbach, D., Drauz, S. R., Braun, M., & Kneiske, T. M. (2020). Pandapipes: An Open-Source Piping Grid Calculation Package for Multi-Energy Grid Simulations. *Sustainability*, *12*(23). https://doi.org/10.3390/su12239899

Lombardi, F., Balderrama, S., Quoilin, S., & Colombo, E. (2019). Generating high-resolution multi-energy load profiles for remote areas with an open-source stochastic model. *Energy*, *177*, 433–444. https://doi.org/10.1016/j.energy.2019.04.097

Lund, H., Thellufsen, J. Z., Østergaard, P. A., Sorknæs, P., Skov, I. R., & Mathiesen, B. V. (2021). EnergyPLAN – Advanced analysis of smart energy systems. *Smart Energy*, *1*. https://doi.org/10.1016/j.segy.2021.100007

OpenStreetMap. (2025). *OpenStreetMap*. https://www.openstreetmap.org

Panitz, F., Behrends, T., & Stange, P. (2022). Software-supported Investment Optimization for District Heating Supply Systems. In *Proceedings of EuroSun 2022 - ISES and IEA SHC International Conference on Solar Energy for Buildings and Industry*. https://doi.org/10.18086/eurosun.2022.04.07

Pfeiffer, J. (2025). *DistrictHeatingSim*. [Computer software]. https://github.com/JonasPfeiffer123/DistrictHeatingSim

Peere, W., & Blanke, T. (2022). GHEtool: An open-source tool for borefield sizing inPython. *Journal of Open Source Software*, *7*(76), 1–4. https://doi.org/10.21105/joss.04406

Python GUIs. (2025). *The complete PyQt5 tutorial*. https://www.pythonguis.com/pyqt5-tutorial/

SAENA. (2025). *Energieportal Sachsen - Themenkarten und Infos*. https://www.energieportal-sachsen.de/

Sachsen. (2025). *Geothermieatlas Sachsen*. https://www.geologie.sachsen.de/geothermieatlas-13914.html

Solites. (2017). *ScenocCalc Fernwärme*. https://www.scfw.de

Sollich, M., Wack, Y., Salenbien, R., & Blommaert, M. (2025). Decarbonization of existing heating networks through optimal producer retrofit and low-temperature operation. *Applied Energy*, *378*(Part A). https://doi.org/10.1016/j.apenergy.2024.124796

Sporleder, M. (2024). *Design optimization of decarbonized district heating systems*. [Dissertation, BTU Cottbus-Senftenberg]. https://doi.org/10.26127/BTUOPEN-6852

Sporleder, M., Rath, M., & Ragwitz, M. (2022). Design optimization of district heating systems: A review. *Frontiers in Energy Research*, *10*. https://doi.org/10.3389/fenrg.2022.971912

STANET. (2016). *STANET®*. [Computer software]. Fischer-Uhrig Engineering GmbH. https://www.stafu.de

TOP-Energy. (2025). *TOP-Energy®*. [Computer software]. https://www.top-energy.de

VDI. (2025). *VDI Standards*. https://www.vdi.de/en/home/vdi-standards

VICUS Software. (2025). *VICUS Districts*. [Computer software]. VICUS Software GmbH. https://vicus-software.com/warmenetzplanung-vicus-districts/

Vieth, J., Westphal, J., & Speerforck, A. (2025). A GIS-based Co-Planning Approach for District Heating Networks. *Energy Proceedings*, *50*, 1–10. https://doi.org/10.46855/energy-proceedings-11423

Wirtz, M. (2023). nPro: A web-based planning tool for designing district energy systems and thermal networks. *Energy*, *268*. https://doi.org/10.1016/j.energy.2022.126575

Wirtz, M., Kivilip, L., Remmen, P., & Müller, D. (2020). 5th Generation District Heating: A novel design approach based on mathematical optimization. *Applied Energy*, *260*. https://doi.org/10.1016/j.apenergy.2019.114158

VÝVOJ INTEGROVANÉHO SOFTWAROVÉHO PRACOVNÍHO POSTUPU PRO PLÁNOVÁNÍ SÍTĚ DÁLKOVÉHO VYTÁPĚNÍ: STRUKTUROVANÝ METODICKÝ PŘÍSTUP

Tento článek popisuje proces zefektivnění stávajících metod koncepce a plánování sítí dálkového vytápění (SDV) prostřednictvím návrhu integrovaného pracovního postupu. Stávající řešení jsou často roztříštěná nebo nedostatečně přístupná a transparentní. V tomto článku integrovaný metodický přístup kombinuje prostorovou analýzu požadavků a potenciálů tepla podporovanou geografickým informačním systémem (GIS), tvorbu a simulaci tepelných sítí a dimenzování generátorů tepla v rámci jednotného pracovního postupu. Metodika je ověřena na základě případových studií a jejím cílem je umožnit transparentní a reprodukovatelné plánování udržitelných tepelných sítí. Vytvořené přístupy jsou výsledkem výzkumného projektu financovaného Saským státním ministerstvem pro vědu, kulturu a cestovní ruch a jsou implementovány v softwaru DistrictHeatingSim s otevřeným zdrojovým kódem, který je veřejně dostupný na GitHubu.

ENTWICKLUNG EINES INTEGRIERTEN SOFTWARE-WORKFLOWS FÜR DIE PLANUNG VON FERNWÄRMENETZEN: EIN STRUKTURIERTER METHODISCHER ANSATZ

In diesem Beitrag wird die Entwicklung von Methoden und Software für die Konzeption und Planung von Fernwärmenetzen vorgestellt. Bestehende Lösungen sind oft fragmentiert oder es mangelt an Zugänglichkeit und Transparenz. In dieser Arbeit wird ein integrierter methodischer Ansatz vorgeschlagen, der die GIS-gestützte räumliche Analyse von Wärmebedarf und -potenzialen, die Erstellung und Simulation von Wärmenetzen sowie die Dimensionierung von Wärmeerzeugern in einem einheitlichen Arbeitsablauf kombiniert. Die Methodik wird anhand von Fallstudien validiert und zielt darauf ab, eine transparente und reproduzierbare Planung von nachhaltigen Wärmenetzen zu ermöglichen. Die entwickelten Ansätze sind das Ergebnis eines vom Sächsischen Staatsministerium für Wissenschaft, Kultur und Tourismus (SMWK) geförderten Vorlaufforschungsprojekts und sind in der Open-Source-Software DistrictHeatingSim implementiert, die auf GitHub öffentlich zugänglich ist.

OPRACOWANIE ZINTEGROWANEGO OPROGRAMOWANIA DO PLANOWANIA SIECI CIEPŁOWNICZEJ: USTRUKTURYZOWANE PODEJŚCIE METODOLOGICZNE

W niniejszym artykule opisano proces zwiększenia efektywności istniejących metod projektowania i planowania sieci ciepłowniczych. Istniejące rozwiązania są często rozproszone lub nie są wystarczająco dostępne i przejrzyste. W niniejszym artykule zaproponowano zintegrowane podejście metodyczne, które łączy opartą na systemie informacji geograficznych (GIS) analizę przestrzenną zapotrzebowania na ciepło i potencjału, tworzenie i symulację sieci ciepłowniczych oraz wymiarowanie urządzeń grzewczych. Metodyka została zweryfikowana na podstawie studiów przypadków i ma na celu umożliwienie przejrzystego i powtarzalnego planowania zrównoważonych sieci ciepłowniczych. Opracowane podejścia są wynikiem projektu badawczego finansowanego przez Saksońskie Ministerstwo Nauki, Kultury i Turystyki i zostały wdrożone w oprogramowaniu open source DistrictHeatingSim, które jest publicznie dostępne na GitHub.