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Decarbonization of District Heating Systems

An integrated assessment of decarbonization pathways through the SEA DHC Simulation Tool

By

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Summary

The decarbonization of the heating and cooling sector is a key challenge in the European energy transition, involving a complex interplay of technical constraints, regulatory pressures, and diverging stakeholder objectives. District Heating and Cooling systems (DHCs) are increasingly seen as strategic infrastructures to support this transition, especially when integrated with renewable energy sources (RES), waste heat (WH), and energy efficiency measures. However, transforming DHCs to meet evolving standards requires coordinated planning, robust technical tools, and shared governance frameworks.

This research develops and applies SEA DHC tool, a modular simulation tool designed to support early-stage DHC planning across three dimensions: thermal demand, generation, and boundary conditions (economic, regulatory, and environmental). The tool performs hourly-resolution analyses, enabling scenario-based assessments of energy demand, technology dispatch, and system costs and emissions. It is structured to be adaptable to existing or potential DHCs, and it offers actionable insights for a range of stakeholders, including public authorities, DHC operators, and industries with valorisable WH. A key innovation of the model lies in its integration: unlike traditional tools that focus separately on generation or hydraulic modeling, building energy performance, or macro-level energy planning, SEA DHC tool combines spatially resolved thermal demand mapping, dynamic generation dispatch, and economic/environmental evaluation in a single framework. Inputs, assumptions, and simplifications are explicitly defined to clarify the scope and limitations of the tool.

The thermal demand sub-model is validated against real data from the Turin district heating system, demonstrating the robustness of the three implemented methodologies. The generation sub-model simulates technology dispatch hourly, while the boundary conditions module supports scenario analysis for CO_2 emissions and system costs.
The model is applied to three district heating systems (DHs) case studies chosen to reflect a range of planning needs, technological contexts, and stakeholder configurations.
In the first application, an existing DH is undergoing a revamping process and considering network expansion. The SEA DHC tool supports decisions on the feasibility of integrating RES and WH sources while maintaining compliance with EED criteria for efficient DHC. The DHC operator, a nearby industrial waste heat provider, and the local municipality are key stakeholders.
The second case study focuses on a greenfield urban area with no DHC. Here, the model is used to assess the environmental impact and economic viability of a new DH, especially regarding emissions reduction and renewable integration. The analysis guides both municipal planners and a potential DHC operator.
The last case study is a mid-sized fossil based DH considering decarbonization pathways while facing potential ETS policy extension. The case explores alternative configurations and evaluates how changes in regulatory boundaries (e.g., ETS expansion) and market structures (e.g., electricity pricing) affect investment decisions. This case supports both private operators and policymakers in assessing the effectiveness of ETS reforms and the robustness of long-term business plans.
In each case, the tool is guided by stakeholder-specific research questions addressing feasibility, competitiveness, compliance, and environmental performance. Through this approach, SEA DHC tool can support informed, context-sensitive decision-making.

Overall, this work contributes to advancing the role of DHCs as enablers of low-carbon urban energy transitions. It highlights the need for integrative tools that bridge the gap between technical modeling, policy design, and spatial planning. SEA DHC offers a replicable and scalable instrument that can inform future regulatory frameworks and investment strategies, helping align local planning efforts with broader European decarbonization targets.