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Environmental and Economic Performance of a Biomass-Solar District Heating System: A Life Cycle Assessment and LCOH Case Study from Austria

Summary

This paper assesses the environmental and economic performance of a real-world biomass district heating (DH) system with solar thermal integration in Styria, Austria. The system comprises three biomass boilers (1,880 kW total), an 1,800 m² solar thermal field (914 MWh/a yield, 11% annual solar share), buffer storage (246 m³), and a 5,000 trm grid serving 149 customers with 6,125 MWh/a of delivered heat. The assessment applies a harmonised LCA/LCOH methodology based on the results of the IEA SHC Task 71. Besides the system perspective, the end-customer perspective enables a direct comparison of lifecycle carbon footprint and heat costs with individual fossil heating systems – a metric that is both scientifically rigorous and directly communicable in planning and policy contexts. Two sensitivity scenarios address biomass supply chain variability and increased solar fraction. Results are intended to provide transparent, quantitative arguments for the broader deployment and public acceptance of high-renewable district heating.

Keywords: life cycle assessment, levelised cost of heat, district heating, solar thermal, biomass, end-customer carbon footprint

Field of application for the findings: District heating planning, renewable heating policy, end-customer lifecycle communication, LCA and LCOH for solar and biomass systems

Addressed audience: LCA and energy system researchers, district heating planners and operators, municipal utilities, renewable energy policy makers

1. Introduction

District heating (DH) systems powered by renewable energy sources are a key element of Europe's heating sector decarbonisation strategy. In Austria, biomass-based DH grids with solar thermal integration have been operated successfully. Despite their technical maturity, systematic assessment of their full environmental and economic performance across the entire lifecycle remains scarce – particularly at the level of the individual end-customer, where comparison with fossil heating alternatives is most directly meaningful for planning decisions and public communication.

Transparent, comparable performance indicators are essential for building the evidence base needed for investment decisions, subsidy design, and public acceptance of renewable DH infrastructure. LCA and LCOH are established methodological tools for this purpose; their combined application to real-world biomass-solar DH systems, expressed consistently from component level down to the individual building connection, remains limited in the literature (Tulus et al., 2016; Mahon et al., 2022). This paper addresses the gap by applying a combined LCA and LCOH framework to a documented Austrian case study system, generating results at both system and end-customer level and comparing them against fossil reference systems. The work was carried out within the framework of IEA SHC Task 71 on Life Cycle and Cost Assessment for Heating and Cooling Technologies (IEA SHC Task 71, 2025).

2. System Description

The case study system is located in Austria (annual average ambient temperature 11.9 °C; beam irradiance 691.9 kWh/(m²·a); diffuse irradiance 581.1 kWh/(m²·a)). It consists of two hydraulically separate boiler stations feeding a common district heating grid. The main station integrates two large biomass boilers (980 kW and 600 kW, 90% efficiency) with a 1,800 m² solar thermal collector field (flat-plate collectors, tilt 35°, south-oriented, specific yield 508 kWh/(m²a)) and two 100 m³ buffer tanks. A second decentralised station houses a smaller 300 kW biomass boiler with a 38 m³ storage. This configuration allows the two large boilers to be shut down during summer, with the small boiler and the solar field jointly covering the reduced seasonal load – significantly reducing wood chip consumption and operating hours of the main units. The grid extends to 5,000 trm and supplies 149 customers.

Key annual performance figures: heat delivered to customers 6,125 MWh/a; heat fed into grid 7,657 MWh/a; solar thermal yield 914 MWh/a (11% annual solar share, rising to up to 57% in summer months); biomass boiler output 7,144 MWh/a; wood chip demand approximately 7,545 MWh/a (around 2,155 t/a at 30% moisture). Overall system efficiency is 90% excluding grid losses and 72% including grid losses. DH supply temperatures are 88 °C (winter) / 79 °C (summer); return temperatures 44 °C / 48 °C.

3. Methodology for Evaluation

The LCA follows ISO 14040/14044 (ISO, 2006) with a cradle-to-grave system boundary, covering manufacturing and installation of all components (solar collectors, storage tanks, boilers, pipework, grid infrastructure), operation including the biomass fuel supply chain and auxiliary electricity, and end-of-life treatment. Background inventory data are taken from ecoinvent, supplemented by component-specific data. Primary impact categories reported are global warming potential GWP100 (kg CO_2eq), cumulative energy demand, and water scarcity footprint.

Two complementary functional units are applied. At system level, the functional unit is 1 MWh of heat delivered to the district heating network, enabling technology benchmarking. At end-customer level, the functional unit is the annual heat supply to a representative residential building connected to the network, expressed as kg CO_2eq per household per year and as annual heat cost in EUR. This end-customer metric is directly comparable to the lifecycle emissions and costs of an individual gas boiler or oil heating system serving the same building – making results communicable without requiring the audience to interpret abstract system-level indicators.

The LCOH is calculated as the net present value of all capital and operational expenditures divided by total lifetime heat production (IEA SHC Task 71, 2025), assuming a 25-year system lifetime. Carbon price sensitivity is evaluated. A fossil systems serve as benchmarks: an individual natural gas condensing boiler at building level. The benchmark separates the contribution of DH infrastructure from that of the renewable fuel and solar integration.

4. Design of Scenarios

Two sensitivity scenarios complement the reference case to bracket the range of environmental and economic performance that can realistically be achieved with this system type:

Scenario S1 – Biomass supply chain variability: The biomass fuel input is varied between Austrian forest residues (short transport distances, low land-use impact) and imported wood pellets or energy crops (higher processing and transport emissions). Biomass supply chain emissions typically dominate the operational GHG balance of biomass DH systems and represent the largest source of uncertainty in the LCA. This scenario makes that uncertainty explicit and quantifiable, providing guidance for operators on the environmental importance of fuel procurement choices and for policy instruments targeting biomass sustainability criteria.

Scenario S2 – Increased solar fraction: The collector area is scaled from 1,800 m² to approximately 2,500 m², raising the annual solar share from 11% to around 18% and further increasing summer coverage. The existing operational setup already demonstrates that the small boiler and solar field together are sufficient to cover summer demand without the large boilers; this scenario quantifies how much additional biomass displacement – and corresponding reduction in lifecycle GHG emissions per connected household – is achievable before additional storage or grid adaptation becomes necessary. The scenario directly supports planning decisions on the value of upfront solar investment in biomass DH systems.

5. Results and Conclusions

Calculations are currently in finalisation. The full paper will present quantitative LCA and LCOH results for the reference case and scenario variation, expressed at system level and per connected household, and set against the fossil benchmark. The end-customer framing is a deliberate methodological choice: lifecycle greenhouse gas emissions and heat costs expressed per household are directly comparable to published data for fossil boilers, making the results useful not only for academic benchmarking but also for planning consultations, subsidy applications, and public communication processes.

The study is expected to confirm lifecycle GHG advantages of the biomass-solar DH system over fossil individual heating at the building level, and to demonstrate that biomass supply chain quality and solar fraction are the two most effective levers available to planners and operators for further improving environmental performance. On the economic side, the carbon price sensitivity analysis will illustrate the conditions under which renewable DH becomes competitive with fossil alternatives – a finding directly relevant to Austrian and European heating decarbonisation policy.

6. References

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