WOOD–SOLAR HYBRIDIZATION FOR SWISS DISTRICT HEATING

Summary

Biomass-based district heating networks (DHNs) in Switzerland are well established, but wood resource constraints increase the interest in alternative renewable heat sources apt at complementing it. Solar thermal can reduce biomass consumption, but the integration strategy strongly impacts the DHN performance and efficiency. Four hydraulic topologies were compared to integrate solar thermal into a biomass-based DHN. Several TRNSYS models, validated with measured data, were combined for a case study in Les Ponts-de-Martel, a town in Neuchatel canton, under 2019 weather and market conditions. The best topology was then compared to grid-connected PV + HP + biomass and PV + groundwater HP systems, with both configurations adopting an ammonia cycle and the DHN operating temperatures, (85–45°C). Results quantify solar fraction, wood savings, emissions (CO, NOx, particulates) and LCOH to allow a comparison of possible solar-biomass solutions capable of reducing resource consumption and sustain DHN decarbonization in Switzerland.

Keywords: district heating, solar-thermal, biomass, thermal energy storage, LCOH, TRNSYS, Switzerland

Field of application for the findings: Solar Thermal, Sustainable and Efficient Districts

Addressed audience: district heating operators, policy makers, business engineers, boiler manufacturers

1. Introduction and motivation

Wood-based district heating networks (DHN) play a central role in Switzerland's heat decarbonization strategy. Yet the sustainable biomass resource remains limited and increasingly constrained by competing uses [1]. A promising complement, solar thermal energy is capable of supplying summer demand and reducing wood consumption. However, integrating intermittent solar heat into biomass systems raises technical, environmental, and economic challenges, particularly regarding partial load operation, thermal energy storage (TES) integration, emissions and heat costs. At the same time, alternative concepts based on photovoltaic (PV) systems coupled with large-scale heat pumps (HP) are gaining traction for DHN applications. The OptiCADSol project [2], funded by the Swiss Federal Office of Energy, has focused on the comparison of several hybrid configurations to identify efficient pathways for low-carbon and resource-efficient DHN development.

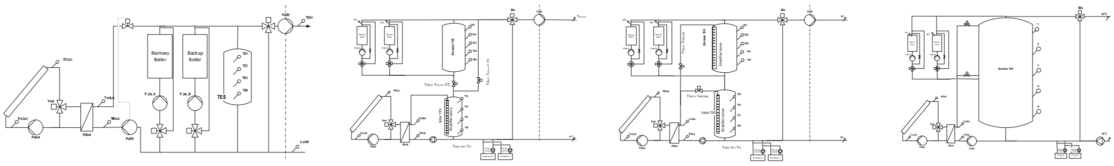
2. Reference system and methods

A detailed dynamic model of a reference biomass-based DHN system was developed in TRNSYS and validated against real consumption data. Based on the existing network of Les Ponts-de-Martel, in the canton of Neuchatel in Switzerland, the DHN boiler room features two wood boilers in cascade (1.2 MW and 0.6 MW) equipped with a buffer thermal storage to smooth operations. Particular attention was given to control strategies, including boiler cascade management, storage state of charge, and return temperature regulation. Emissions of CO, NOx, and particulate matter were quantified considering the different operating phases using emission factors of reference published by QM Bois, a professional association dedicated to biomass energy development [3]. Several TRNSYS variants were then designed to include a solar thermal field, modelled and validated on measurement data from the SolarCADII monitoring project [4] to gain insight on the technical, environmental and economic performance of different hydraulic integrations.

3. Wood–solar integration concepts

Four hybrid integration concepts were developed to explore how solar thermal energy can complement wood-based heat production, and they are shown in Figure 1:

- Circuit 1: the solar field is connected in parallel with the biomass boilers and the solar heat is injected on a common TES at nominal DHN distribution temperatures.



Circuit 1 Circuit 2 Circuit 3 Circuit 4

Figure 1: Synoptic view of the four hydraulic solar integration concepts investigated in the OptiCADSol project.

- Circuit 2: the solar field heats up a dedicated solar TES connected in series after the flue gas condensers and before the biomass stack, with heat transferred either to the boiler inlet or directly to the DHN depending on temperature.
- Circuit 3: the solar field heats up a dedicated solar TES or directly the biomass TES when temperatures allow it. The biomass producer cannot be bypassed.
- Circuit 4: Solar and biomass energy are integrated on the same TES, with solar preheating the lower layers and biomass supplying the upper layers.

All concepts were modelled with high vacuum flat plate collectors capable of producing temperatures around 85–90 °C with high efficiencies, yielding about 45% of the annual solar irradiation at the DHN site. Subsequently, a cash flow model was used to include a comparison of the cost of heat. A series of indicators were adopted to characterize the production performance, the emissions and the economics for each integration concept and for several sizes of solar field and TES. Sensitivity analysis was then carried out to evaluate the impact of the aperture area of the solar field (A_{SF} in [m^2]) and the specific volume of the TES ($V_{SP,TES,}$ defined as m^3 of TES for each m^2 of solar collectors and expressed in [m^3/m^2]). The specific solar yield, in [$kWh/m^2/y$], allowed quantifying the annual solar yield of one m^2 of solar collectors, while the Solar Fraction (SF, in [%]) allowed showing the results depending on the fraction of the final energy demand covered by solar thermal energy. Environmental impacts, on the other hand, were studied through the change in CO, NOx and particulate emissions, relying upon the comparison of the hybrid plant annual emissions referred to the DHN annual production, in [g/kWh]. An evaluation of the Levelized Cost of Heat (LCOH, in [CHF/MWh]), allowed to establish a clear benchmark for comparing these solutions among them and to traditional production systems, including those relying on HP. Results show that the hydraulic concept of Circuit 2 features the best technical performance, while allowing to limit the increase in CO emissions and decreasing the NOx and particulate emissions of the hybrid plant. The integration concept of circuit 2, furthermore, offers the largest decrease in wood consumption. Yet, due to the impact of amortizations, the hybrid biomass-solar heat is competitive only for biomass energy production prices exceeding 120 CHF/MWh and if current public incentives and subsidies for replacing fossil-fuel-based systems are applied. In this case, in fact, the solar LCOH drops significantly, from about 90-100 CHF/MWh to approximately 50 CHF/MWh in the optimal layout.

4. HP based systems

The project investigated also HP systems as an alternative or complement to biomass-based DHNs. Two configurations were modeled in TRNSYS to compare with the hybrid wood–solar solution based on Circuit 2 hydraulics. The first was a bivalent system combining a biomass boiler with an (indirect) air-source HP and a PV array. The HP covers the summer load, replacing the smaller 600 kW boiler of the reference DHN system, while the PV system has been studied in two variants. In the "Grid" variant, the HP operated continuously using grid electricity, whereas in the "Island" variant, it is limited to electricity produced by the PV array. In both variants, excess PV production was fed back to the grid under the Swiss feed-in tariff program. The second configuration was a monovalent groundwater-source HP supplying the entire DHN, coupled with a PV field and a TES of a capacity equivalent to 1 hour production to smooth operation and reduce cycling. Both HP technologies were modelled on simple ammonia cycles capable of delivering high-temperature heat suitable for DHN operation (85–90 °C). As in the case of the solar thermal variants, a series of indicators were used to study the impact of the TES volume and the PV array size on the technical, environmental and economic performance of the HP based solutions. Solar fraction was computed as the fraction of heat produced by the HP from PV generated electricity, while the plant self-consumption was calculated as the ratio between PV

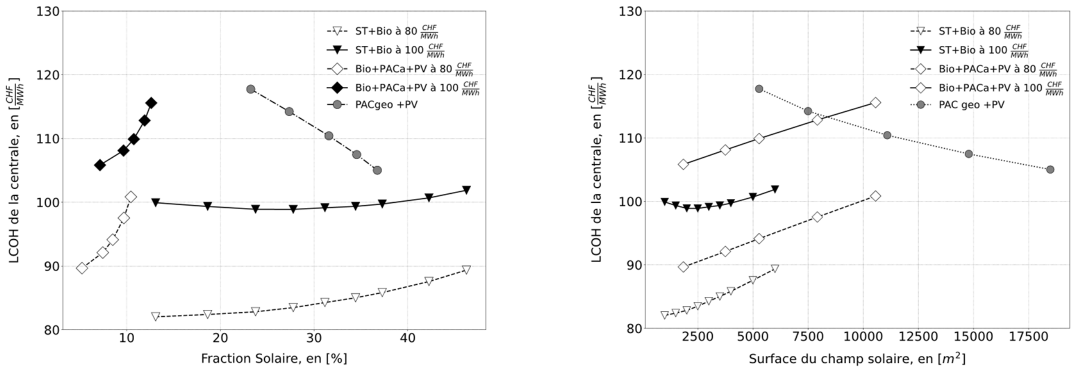


Figure 2: Comparison of the LCOH computed for hybrid solar-biomass solutions and installation based on HP as a function of the solar fraction FS (left) or the aperture area of the solar field (right).

generated electricity consumed by the HP and the PV production. CO2 equivalent emission factors for the HP based systems were derived by adopting a carbon content hourly profile for Switzerland and for 2019 [5], while CO, NOx and particulate emissions for the biomass-HP case were quantified as for the solar thermal case. A separate economic model complemented by a real-market electricity tariff allowed finally to compare the LCOH for the best hybrid solution based on solar thermal (i.e. Circuit 2) to those based on HP, as shown in Figure 2 (right) as a function of FS and as a function of the solar field area (right in Figure 2). In bivalent HP scenarios, the high investment costs of the HP are difficult to amortize due to the limited number of operating hours during which it can run, as biomass is prioritized in winter. Even in monovalent HP configurations, production costs remain higher than those of solar thermal heat unless the required demand coverage by solar electricity surpasses 50%. At this level, the feed-in tariff leverage allows the LCOH of a groundwater HP DHN plant to be lower than the solar thermal solution, even with incentives. However, this comes at the cost of a much higher surface area required for the PV array compared to the solar thermal field.

5. Conclusions

The integration of solar thermal energy into wood-fired district heating networks is a robust and effective strategy for preserving limited biomass resources and help decarbonizing the Swiss heat supply. The broad adoption of wood-solar hybrid systems, in fact, could save approximately 700 GWh of wood annually potentially reaching 1 TWh/y by 2050, if the foreseen deployment of district heating infrastructure takes place [6]. It would require approximately 1.5 million m² of solar collectors, which is a relevant surface in a country with high land-prices like Switzerland, but it would represent a robust pathway for preserving limited biomass resources while supporting the decarbonization of the national heat supply. Wood-solar hybridization is a practical and scalable pathway to reconcile energy efficiency with the sustainable use of natural resources, thanks also to the current "favorable" policy framework for solar district heating in Switzerland.

6. References

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