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Hybrid Solar-Biomass with Energy Storage Comprehensive Analysis for District Heating Systems

Juan José Roncal Casano[1][https://orcid.org/0000-0003-1835-1303], Paolo Taddeo[2][https://orcid.org/0000-0001-6032-6844], Javier Muñoz-Antón[1][https://orcid.org/0000-0002-1980-0863], Joaquim Romaní Picas[2][https://orcid.org/0000-0002-7111-3681], Javier Rodriguez Martín[1][https://orcid.org/0000-0003-1451-0856], and Alberto Abanades[1][https://orcid.org/0000-0003-0179-5987]

[1] Universidad Politécnica Madrid, Spain

[2] Fundació Institut de Recerca en Energia de Catalunya

Abstract. This study analyses the effect of solar field size, biomass boiler and thermal storage capacity for a time dependant demand. The main results to obtain from the simulation will be solar share, biomass consumption and annual coverage with the proposed systems and a selection of the optimum size of these variables for the study case design. Results gathered show that, while there is an increment in solar energy obtained while selecting bigger solar panel areas, tank relations for these big systems show improvement in smaller sizes, visible in the increment of biomass energy used when bigger storage sizes to solar collector areas used.

Keywords: Storage, Simulation, Design

1. Introduction

Nowadays district heating networks are becoming increasingly popular as a way of providing heat to large urban areas in a more sustainable and efficient manner. Several alternatives to implement renewable energy sources are present while hybridising these systems [1], and solar thermal collectors are one of the most promising options for integration into existing district heating systems.

One of the technologies more widely used for generating heat in existing district heating systems is boilers, particularly natural gas or coal-fuelled, which are not renewable and emit greenhouse gases [2]. Therefore, the study of the integration of biomass boilers to change existent boilers, and the implementation of parabolic trough solar thermal collectors as to reduce the amount of boiler energy required in the district heating network, is crucial for achieving a more sustainable and efficient system.

Hybrid district heating systems modelling shows the challenge in correctly identifying key design variables which can deeply affect results. These results could be the biomass consumption, the solar share, the demand coverage while main variables are related with the biomass boiler nominal power, solar field size and type, and storage system size and type.

Once main variables are identified, the identification of the main goal is required, the optimization variable. Sometimes several variables must be optimized at the same time, and then there appears a compromise solution in order to achieve the optimum, i.e., when it is required the cheaper solution with 100% heating demand coverage and maximum reduction of biomass consumption.

This study analyses the effect of solar field, biomass boiler and thermal storage sizes for a fixed power related to a time dependant demand. The main results to obtain will be solar share, biomass consumption and annual coverage with the proposed systems.

Special attention will be paid to tank design volume in correlation with Solar panel area selected. As according to regulations this value is advised between 0.05-0.09 m^3/m^2 emphasis will be made to validate this value in complex scenarios [3].

2. Methodology

The optimization process involves three distinct steps:

First, the simulation of all scenarios is conducted using TRNSYS 18 (TRaNsient SYstems Simulation Program) software [4]. The specific simulation for each technology and the approach to constructing complex models are thoroughly explained in references [5], [6], and will be tested on appropriate operational conditions towards the conclusion of the project.

Second, JEPlus software, which is free, is utilized to conduct a parametric analysis of various equipment sizes (which will be showed later) [7].

At last, the calculation of the levelized cost of energy and emission factor is derived from the data obtained in the preceding stage, employing the methodology outlined in the reference [8], using python scripts.

3. Study case

The work already done in the framework of WEDISTRICT project provide us validated tools for simulation of different scenarios, combining several technologies for a district heating system design [6]. These features adapt to the goals referred in the introduction, where the transient behaviour must be taken into account in order to design and optimize the main characteristics of the proposed district heating facility (Figure 1). In TRNSYS macros will be used, which have been identified by the letter “M” followed by three numbers.

The system (visible in Figure 1) consists in a parabolic trough collector array (PTC) macro M120, which charges a water tank (M210) and then is paired with a biomass boiler macro (M310). These two are given priorities by the interconnecting macro (M910). Then, a network macro is used (M730) which is connected to the demand macro (M810) which interprets the demand curve supplied and translating it to a flow.

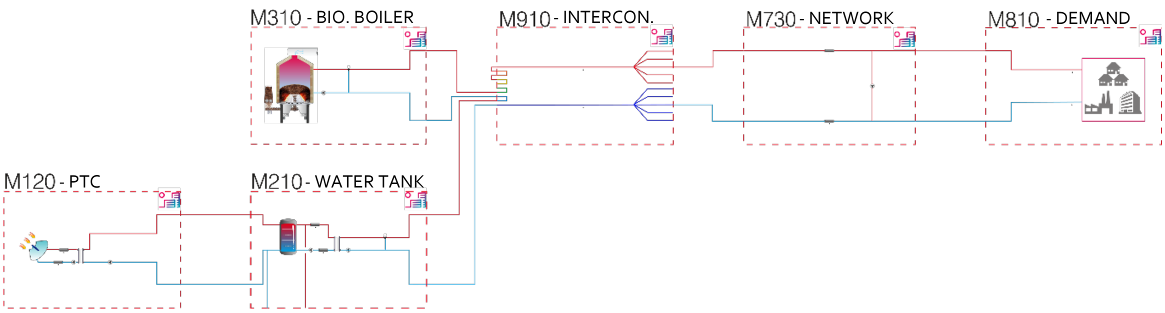
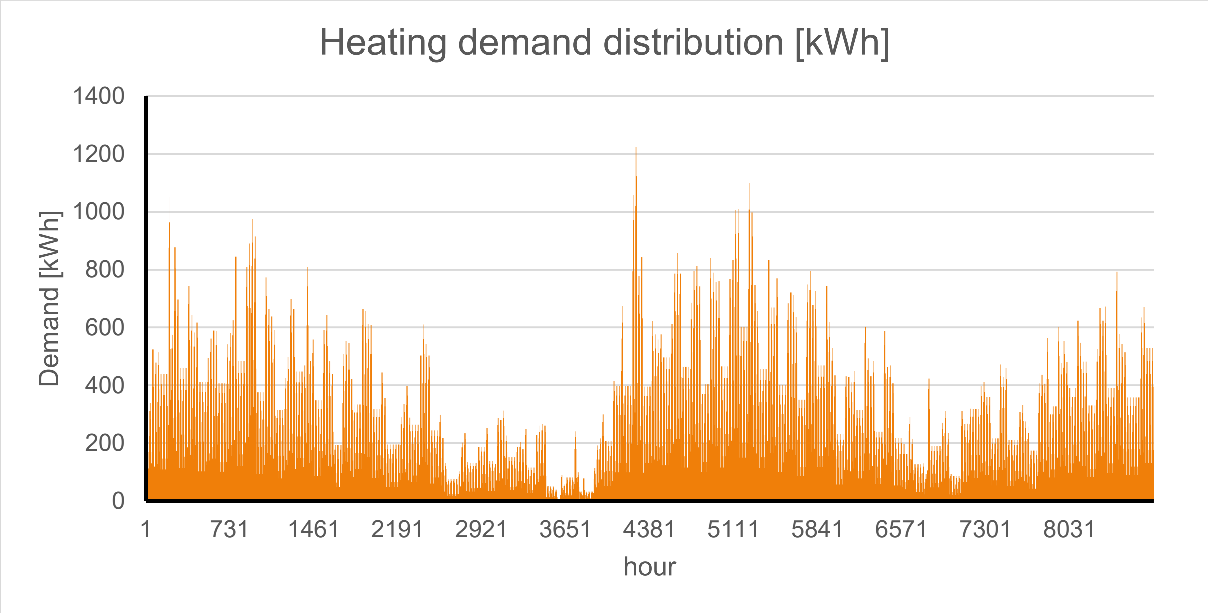


Figure 1. District heating network analyzed.

This study will serve the heating demand shown in Figure 2, where a monotonic curve view is also presented. This demand does not consider domestic hot water generation as it covers only the DHC network. A conservative design value for nominal power in the heating system is 815kW, that means a coverage of 98.5%, but other values as i.e., 700 kW with a coverage of 96% could be useful for this theoretic analysis.



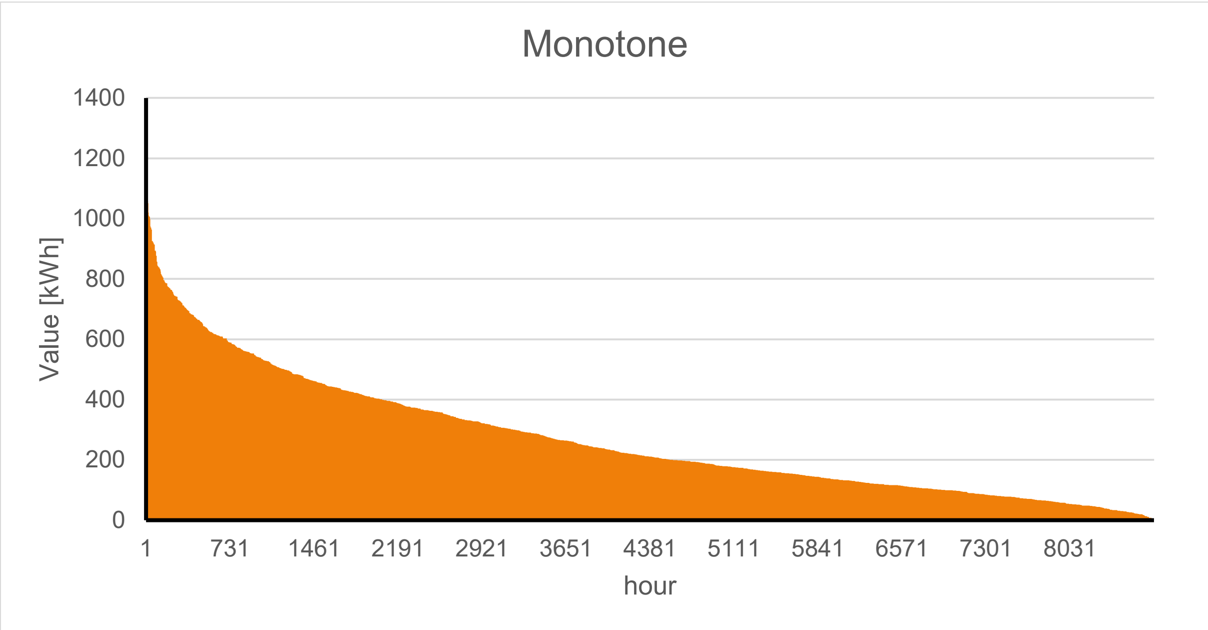


Figure 2. Heating demand distribution for selected place, Alcala de Henares, Spain.

For the selected heating system different combinations of solar field size, boiler nominal power and thermal energy storage size are analyzed in terms of solar share, biomass consumption and demand coverage.

Studies will be carried out paying specific attention to tank sizing regarding relations to solar area.

A value of 0.05 m3/m2 will be considered as nominal design and a parametric analysis, ranging from 0.5-1.8 times this value, will be considered with 0.1 steps, concluding in a variation for each collector size from 0.025 m3/m2 to 0.09 m3/m2 to see if there is any gain to be obtained from selecting these combinations.

Boilers with capacities from 520 to 840 kW have been simulated, with a 20 kW step.

Solar panels capacities from 500 m2 to 1300 m2 have also been used for this analysis with a 100 m2 step.

Table 1. Simulation cases summary.

Variable	Initial Value	Final Value	Step
Tank Volume coef.	0.025 m^3/m^2	0.09 m^3/m^2	0.05 m^3/m^2
Boiler Capacity	520 kW	840 kW	20 kW
Solar Collector Area	500 m^2	1300 m^2	100 m^2

Considering these simulation scenarios 5950 runs are obtained which will be filtered to keep the ones which fulfill the demand profile of the case study.

The ones inside a 95% spectrum of covered demand were kept, which led to 1984 cases able to comply with the requirement aforementioned.

For economical purposes, electricity prices were taken from Red Eléctrica Española, selecting 118.7 €/MWh corresponding to the mean price of electricity in Spain during the year 2021 [9]. For Biomass prices a sectorial site gathering prices in different formats was taken, selecting a final value of 51.7€/MWh corresponding to biomass pellets sold in bulk [10].

For economical calculations the Levelized cost of energy (LCOE) was used, which is a measure of the average net present cost of energy over the system lifetime. It is frequently used to compare technology alternatives for energy generation. LCOE is particularly useful when a high upfront investment is required while a reduced operation costs exist, as it is the case with systems with a high renewable energy share. The levelized cost of energy calculation is a methodology that discounts the time series of expenditures and incomes to their present values in a specific base year. It provides the costs per unit of energy generated which are the ratios of total lifetime expenses (net present value) versus total expected energy generation, the latter also expressed in terms of net present value. These costs are equivalent to the average price that would have to be paid by consumers to repay all costs with a rate of return equal to the discount rate. All the calculations done for the calculation of this KPI are further explained in Deliverable 2.2 of the WEDistrict Project and the corresponding article [8].

4. Results

The goal is to find the case that fulfills the demand without compromising the LCOE cost, a value in which the smallest boiler possible is paired with the greatest collector area tested arise.

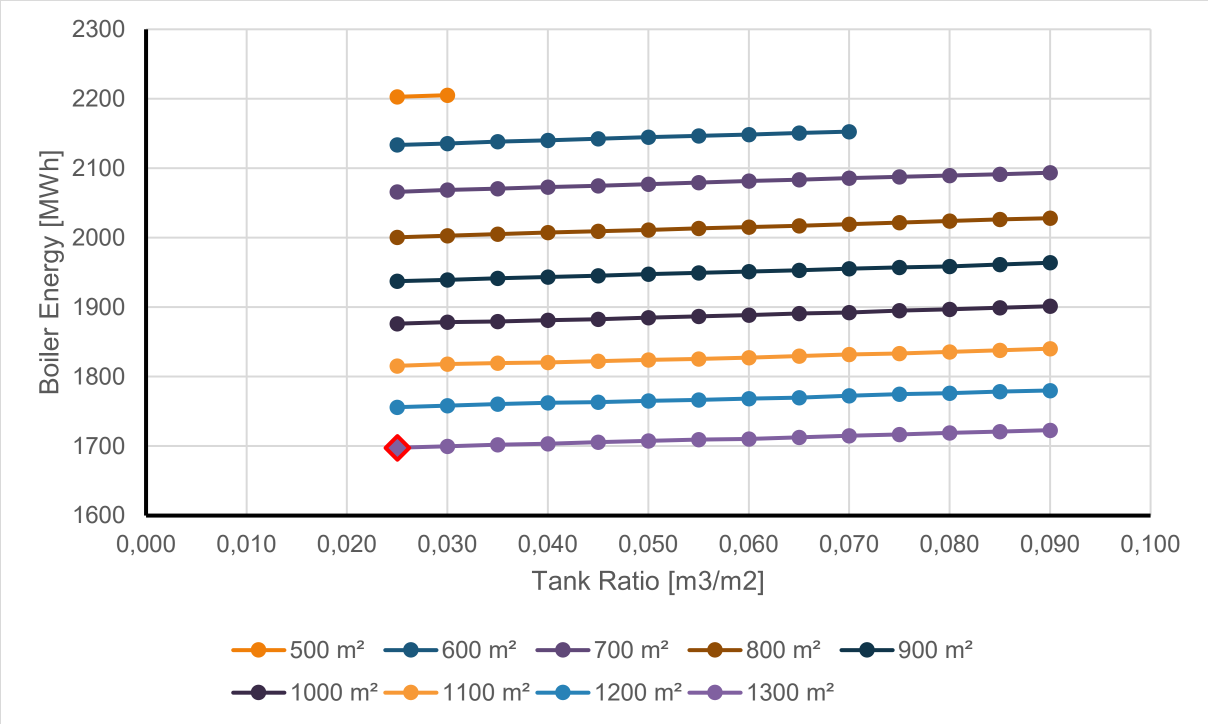


Figure 3. Boiler Energy [MWh] vs Tank Ratio for 840 kW boiler installation with different collector areas [m^2].

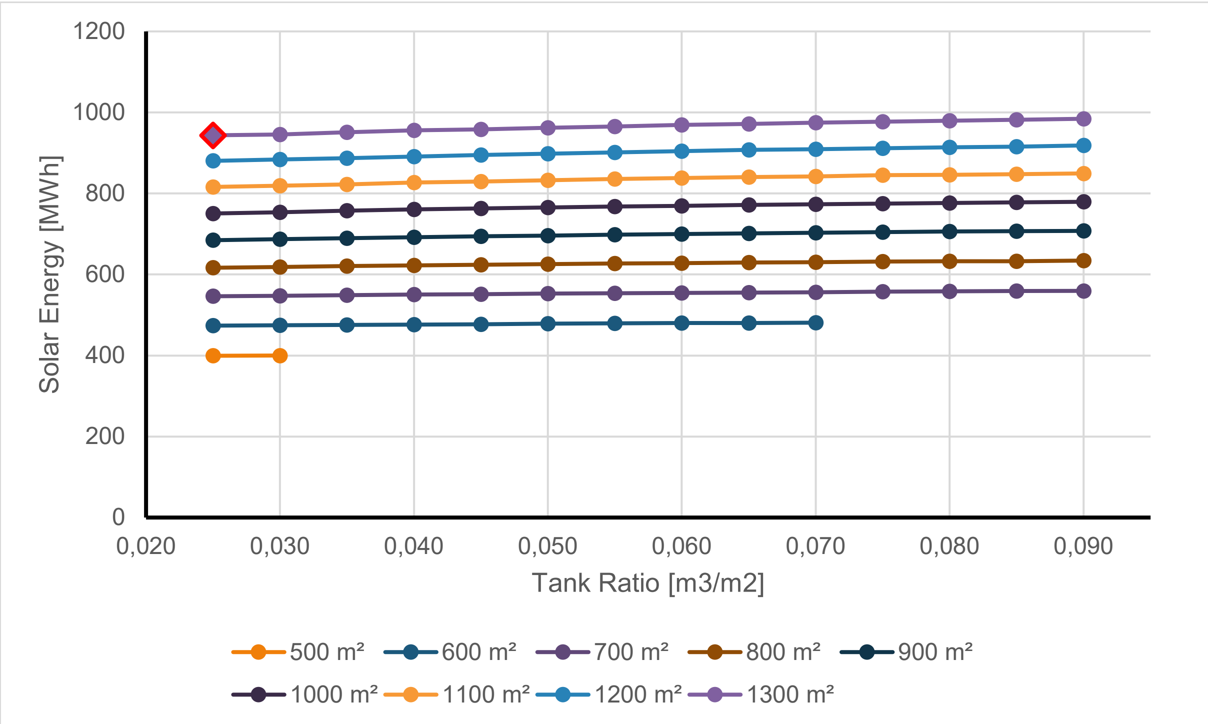


Figure 4. Solar Energy [MWh] vs Tank Ratio [m^3/m^2] for 840 kW boiler installation with different collector areas [m^2].

The different boiler size options prove to be only a point in which broader possibilities of smaller collector areas arise. Due to this fact, results for the biggest option available are shown to compare with all the possible collector sizes.

Comparing both Figures (Figure 3 and 4) we can arrive at the conclusion that the tank size and collector size which generate the best results from a technical point of view (reducing boiler energy and maximizing solar output), would be at first glance the biggest tank ratio possible combined with the highest collector possible, but after seeing that this combination leads to a higher boiler energy production, we can incur that this additional solar energy produced will be used to cover the tank higher heat losses. The fact that biomass boiler energy proves to be lowest in the smallest tank case gives us a good standing point as to state that the case with the smallest tank and the biggest collector area to be the best case. The marked case refers to the only available option for a boiler capacity of 540 kW.

Table 2. Selected case KPIs.

Tank ratio [m^3/m^2]	Tank Volume [m^3]	Biomass Boiler Cap [kW]	Solar Collector Area [m^2]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
0.025	32.5	520	1300	65.2	32.72

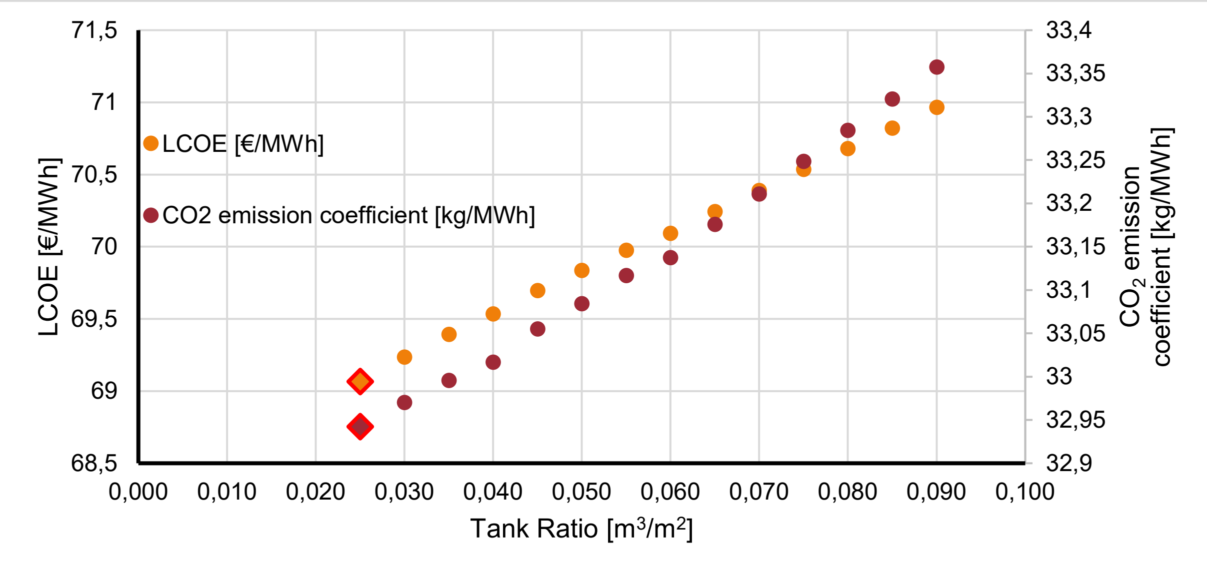


Figure 5. LCOE [€/MWh] and CO2 emission coefficient [kg/MWh] vs Tank Ratio [m3/m2] for 840 kW boiler and 1300 m2.

A good analysis to be made is the variation of these results with prices taken from this year, in which, some values have seen big variations due to the European context. Considering the medium price of electricity up to the second semester (198.6 €/MWh) and the price of biomass in bulk for this period (74 €/MWh) LCOE values for the system show a great increment, shown in Table 3.

Table 3. Comparison of selected case with new economical parameters.

Tank ratio [m^3/m^2]	Tank Volume [m^3]	Biomass Boiler Cap [kW]	Solar Collector Area [m^2]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
0.025	32.5	520	1300	84.33	32.72
=	=	=	=	+29.3%	=

5. Conclusion

Through a comparative analysis of the results, it can be deduced that achieving optimal technical outcomes (lowering boiler energy consumption and maximizing solar output) involves utilizing the largest possible tank ratio in combination with the highest achievable collector size. However, this approach may result in excess heat production by the boiler due to increased solar input, necessitating additional usage to compensate for greater losses from larger tanks. Contrarily, observations reveal that smaller tank sizes yield lower biomass boiler energy requirement thereby confirming that an ideal system would comprise of reduced tank dimensions alongside a maximized collector area.

Data availability statement

Most data cited in this paper can be accessed through its declared site in the References.

Author contributions

Juan José Roncal Casano: Conceptualization, Methodology, Software, Writing - Original Draft, Formal analysis. **Paolo Taddeo**: Conceptualization, Methodology, Software, Writing – review and editing. **Javier Muñoz-Antón**: Conceptualization, Methodology, Visualization. **Joaquim Romaní Picas**: Supervision, Methodology. **Javier Rodriguez Martín**: Writing - Original Draft, Methodology, Software, Supervision. **Alberto Abanades**: Supervision.

Competing interests

The authors declare no competing interests.

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References

1. M. A. Sayegh *et al.*, "Trends of European research and development in district heating technologies," *Renewable and Sustainable Energy Reviews*, vol. 68. Elsevier Ltd, pp. 1183–1192, Feb. 01, 2017. doi: 10.1016/j.rser.2016.02.023.
2. C. Vazquez and M. Victoria, "D2.3 District Heating and Cooling Stock at EU level."
3. M. C. Rodríguez-Hidalgo, P. A. Rodríguez-Aumente, A. Lecuona, M. Legrand, and R. Ventas, "Domestic hot water consumption vs. solar thermal energy storage: The optimum size of the storage tank," *Appl Energy*, vol. 97, pp. 897–906, 2012, doi: 10.1016/j.apenergy.2011.12.088.
4. S. A. Klein and et all, "TRNSYS 18: A Transient System Simulation Program," *Solar Energy Laboratory, University of Wisconsin, Madison, USA*, 2017. http://sel.me.wisc.edu/trnsys. (accessed Jun. 15, 2022).
5. Alberto Abánades, "Analysis of the experimental district heating and cooling facility in Alcalá in the framework of the W.E. District Project," in *16th International Conference on Heat Transfer, fluid Mechanics and Thermodynamics*, Aug. 2022, pp. 150–157.
6. J. J. Roncal-Casano, "Development of TRNSYS Macros for Solar Resource Integration in a District Heating and Cooling Network: W.E. DISTRICT Project," in *Solar Paces 2021*, https://doi.org/10.1063/5.0149410.

7. Y. Zhang, “Use jEPlus as an Efficient Building Design Optimisation Tool,” CIBSE ASHRAE technical symposium, 2012. [Online]. Available: https://www.researchgate.net/publication/304404398
8. A. Ivančić, J. Romaní, J. Salom, and M. V. Cambronero, “Performance assessment of district energy systems with common elements for heating and cooling,” *Energies (Basel)*, vol. 14, no. 8, Apr. 2021, doi: 10.3390/en14082334.
9. Red Eléctria Española, “COMPONENTES DEL PRECIO FINAL Y ENERGÍA DEL CIERRE (€/MWh | MWh),” Jun. 2022. COMPONENTES DEL PRECIO FINAL Y ENERGÍA DEL CIERRE (€/MWh | MWh) (accessed Jun. 15, 2022).
10. AVEBIOM (Asociación Española de Valorización Energética de la Biomasa), “Índice AVEBIOM Precio Medio Pellets de Madera al consumidor final,” Jul. 18, 2022. https://www.avebiom.org/proyectos/indice-precios-biomasa-al-consumidor?language_content_entity=es (accessed Jun. 15, 2022).