THE WEDISTRICT TOOL: AN OPEN-ACCESS WEB APPLICATION TO SUPPORT DECISIONS ON DISTRICT HEATING AND COOLING PROJECTS AROUND EUROPE.

Alberto Abánades[1*], Juan José Roncal-Casano[1], Javier Rodríguez-Martín[1], Joaquim Romaní[2], Santiago Escudero[2], María Guadalupe Rodríguez[3], Nataliia Diatlova[3], Federico Bava[4], Sebastian Wulff[4], Jon Martínez Fontecha[5]

[1] Universidad Politécnica de Madrid, José Gutiérrez Abascal 2, 28006 Madrid, Spain

[2] Institut de Recerca en Energia de Catalunya (IREC), Jardins de les Dones de Negre 1, 08930 Sant Adrià de Besòs Barcelona, Spain

[3]Atos, Albarracin 25, 28037 Madrid, Spain

[4]Rambøll, Hannemanns Allé 53, 2300 København S, Demark

[5] Acciona, Anabel Segura 11, 28108 Alcobendas, Spain

* Corresponding Author: alberto.abanades@upm.es

ABSTRACT

Integrating renewable energy sources into district grids effectively is crucial to achieving decarbonization goals. Therefore, it is imperative to have tools that facilitate the assessment and planning of these systems. The WEDISTRICT project has developed and tested various renewable energy-based heating and cooling systems. The knowledge gathered during the project has led to the creation of the WEDISTRICT tool. This tool is based on a database built from a series of simulations carried out with TRNSYS. With this tool, a user could preliminarily assess renewable district heating and cooling systems. This work explains how the tool was developed and demonstrates its functionality and capabilities in a case study. The tool is expected to enhance knowledge, acceptance, and planning of heating and cooling networks.

1 INTRODUCTION

Nowadays, heating and cooling demands represent a significant part of total energy consumption worldwide. In Europe, heating and cooling are responsible for 35 % of greenhouse gas (GHG) emissions. Current climatization demand is mainly covered by fossil fuels (EEA, 2022). According to Eurostat (2023), for the year 2021, only 23% of the heating and cooling demand was covered by renewable energies. If decarbonization objectives are to be achieved, renewable energies must be incorporated as a matter of urgency.

The WEDISTRICT project aims to test different renewables technologies (solar collectors, innovative thermal storage systems, advanced absorption chillers, biomass boilers and geothermal heat pumps) in three demosites (Lulea (Sweden), Cordoba (Spain) and Bucharest (Romania)) to demonstrate their technical feasibility. These demosites are complemented by 11 virtual demonstrations to test the replicability of the proposed solutions in different European regions and either for designing new or retrofitting existing district heating and cooling (DHC). Solutions based on WEDISTRICT technologies are proposed for each of these virtual demonstrations. The alternatives are evaluated in order to identify the most cost-effective solution.

Simulations, planning, and assessment tools are indispensable to determine the viability of integrating renewable energies into district heating and cooling systems (Sartor, 2017). Allegrini et al. (2015) present a detailed list of twenty tools for assessing the district heating and cooling system.

The knowledge acquired throughout the WEDISTRICT project has enabled the development of a calculation tool for renewable district heating and cooling systems: the WEDISTRICT tool. This tool is a user-friendly and easily accessible web tool designed to conduct a preliminary suitability analysis

https://doi.org/10.52202/077185-0104

of new renewable district heating and cooling systems. The tool utilizes an extensive database generated with TRNSYS (Klein, 2017) simulation models developed and tested throughout the project. Using this tool, users can calculate various technical and economic key parameters (emissions, CO_2 factor and levelized energy cost) to determine the feasibility of a project and select the best solution before starting the detailed design of the system. Compared to other tools, this open-access application allows preliminary assessments of a DHC (District Heating and Cooling) system incorporating various renewable energy sources for users of all levels, from non-technical to expert profiles. In addition, its modular design allows for easy updates of models and data, making it simple to incorporate new technologies into the tool.

2 METHODOLOGY

WEDISTRICT tool works according to the diagram illustrated in Figure 1. Firstly, the user chooses a location and inputs the data for heating and cooling demands and the price, emissions, and primary energy factors for different fuels. Next, the user selects a system layout and enters the economic data (CAPEX and Fixed OPEX) for each technology of the chosen system. WEDISTRICT tool queries a database and provides optimal solutions based on input data. The following sections will explain each of the blocks.

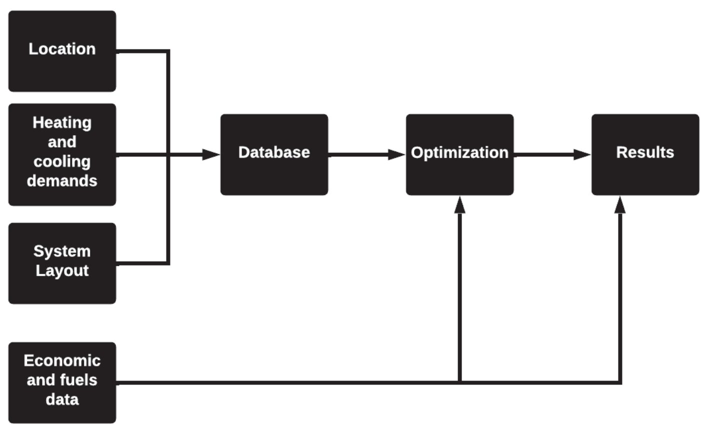

Figure 1: Flow chart of the WEDISTRICT tool.

2.1 Location

The WEDSITRICT tool allows the user to select one of the locations in Table 1. These locations have been considered representative of the different climates present in Europe according to the Köppen-Geiger classification (Peel et al. 2007).

Table 1. Data of the different locations.

City	Heating degree days	Cooling degree days
Rome	808	380
Madrid	1647	484
Paris	1938	96
Bucharest	2219	331
Stockholm	3319	18

https://doi.org/10.52202/077185-0104

2.2 Heating and cooling demands

The heating and cooling profiles are created by modifying the reference profiles corresponding to the location using values entered by the user based on equations 1 and 2.

$$Q_{H,i} = \alpha \cdot Q_{H,i,ref} \quad (1)$$

$$Q_{C,i} = \alpha \cdot \beta \cdot Q_{C,i,ref} \quad (2)$$

Where $Q_{H,i}$ $Q_{C,i}$ are the heating and cooling demands at hour i, α is the ratio between the annual, $Q_{H,i,ref}$ and $Q_{C,i,ref}$ are heating and cooling demands at hour i for the reference profile and β is the ratio between the annual heating and cooling demands. The parameter α varies from 0.2 to 2. The values of the parameter β are listed in Table 2, which are derived from references Hotmaps (2019) and Stratego (2016).

Table 2. Values for the parameter β (Hotmaps, 2019 and Stratego, 2016)

City	Values
Rome	0.05,0.1,0.15,0.2,0.25,0.3,0.35
Madrid	0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8
Paris	0.04,0.09,0.14
Bucharest	0.09,0.14,0.19
Stockholm	0.04,0.09,0.14

The reference heating profile is estimated by summing up three contributions: space heating, domestic hot water and network losses. The space heating profile is based on the heating degree methodology described in the reference (Eurostat 2023b). The domestic hot water is calculated as a fraction of the annual SH demand obtained from reference (Eurostat 2023c). A value has been taken for each country. This value remains constant for each day of the year. The network losses are assumed to be 18 % of the yearly heating demand. This value has been established considering that, according to Törnros (2016), annual heat losses are usually higher than 16 %.

The reference cooling profile is the sum of space cooling and network losses. The space cooling profile is calculated using conversion tables that consider the occupation profile of the buildings. These tables provide information on how the ambient temperature relates to the fraction of the peak cooling load for each hour of the day. The peak cooling load, equivalent to 100%, is assigned to the highest hourly ambient temperature. The yearly thermal losses from the network are assumed to be 3% of the yearly cooling supplied to the DC network.

The heating network has a supply temperature of 90 ºC and a return temperature of 70 ºC. The cooling network operates with a supply temperature of 6 ºC and a return temperature of 12 ºC. These temperatures remain constant throughout the year.

2.3 System layout

The following system layout are included in the WEDISTRICT tool:

- **DH Basic**: This system consists in a biomass boiler and gas boiler. The biomass boiler covers the base demand while the gas boiler covers the peak demand.
- **DH Basic + Solar technology**: This system adds to the DH Basic a solar field with the corresponding storage system. The user can choose from the following solar technologies:

https://doi.org/10.52202/077185-0104

parabolic trough collectors, Fresnel collectors, and a innovative flat-plate collectors tested in the WEDISTRICT project (WESSUN).

- **DHC Basic**: This system adds to the DH basic an absorption chiller and a compression chiller to cover the cooling demand. The absorption chiller covers the base demand while the compression chiller covers the peak demand.
- **DHC Basic+ Solar technology:** This system adds to the DHC Basic a solar field with the corresponding storage system. The user can choose from the following solar technologies: parabolic trough collectors, Fresnel collectors, and WESSUN.

The technologies presented on each system layout are sized according the following criteria:

- **Biomass boiler nominal power:** It is calculated a ratio of the maximum heating demand. Three ratios are considered: 0.5, 0.6 and 0.7. The efficiency of the biomass boiler is 0.89.
- **Gas boiler nominal power:** It is calculated as the difference between the maximum heating demand and the capacity of the biomass boiler. The efficiency of the gas boiler is 0.95
- **Solar field area and hot water tank:** The solar filed area is calculated according to the equation 3.

$$A_{SF} = \frac{c \cdot \bar{Q}_H}{\eta_{SF} \cdot \overline{DNI}} \tag{3}$$

Where $\bar{Q}_H$ is the average daily heating demand during the summer [kWh], $\overline{DNI}$ is the average daily solar radiation available during the summer [kWh/m^2], η_{SF} is the collector efficiency [-] and c is a scale factor [-]. The scale factor c takes the values 0.5, 1 and 2

The hot water storage volume is calculated from equation 4

$$V = \frac{3600 \cdot c \cdot \rho \cdot \bar{Q}_H}{c_p \cdot \Delta T} \tag{4}$$

Where $\bar{Q}_H$ is the average daily heating demand during the summer, ρ is the water density [m^3/kg], c_p is the specific heat capacity of the water [kJ/(kg·K)], ΔT is the difference between the maximum and minimum water temperature inside the tank [K] and c is a scale factor [-]. The scale factor c takes the values 0.5, 1 and 2. A value of 20 K is assumed for the ΔT.

Table 3 includes the area of the solar field and hot water storage volume (scale factor 1) for each location.

Table 3. Solar field area and hot water storage volume (scale factor 1) for each location.

	ROM	MAD	PAR	STO	BUC
Solar field area [m^2]	2497	2086	2819	1910	2792
Hot water storage volume [m^3]	414	430	366	335	326

- **Advanced absorption chiller and compression chiller nominal power:** They are fixed as a percentage of the peak cooling demand, considering the location (Table 4). These values are obtained through preliminary simulations. The COP of the advanced absorption and compression chiller are 0.83 and 3.5, respectively. The advanced absorption chiller is a novel technology developed within the WEDISTRICT project, improving the COP by recovering condensation heat. A detailed description of this equipment can be found in reference WEDISTRICT (2021).

https://doi.org/10.52202/077185-0104

Table 4. Sizing of the advanced absorption chiller and the compression chiller air/water.

	ROM	MAD	PAR	BUC	STO
Advanced Absorption chiller	0.2, 0.3 ,0.4	0.2, 0.3 ,0.4	0.2, 0.3 ,0.4	0.3, 0.4 ,0.5	0.2, 0.3 ,0.4
Compression chiller air/water	0.7, 0.8, 0.9	0.7, 0.8, 0.9	0.7, 0.8, 0.9	0.7, 0.8	0.7

2.4 Economic and fuel data

The tool provides the user with default values of the following data considering the location:

- Specific costs of each technology
- Emissions coefficients and primary energy factors for each energy carrier
- Price for each fuel.

These values have been obtained from the references (Eurostat 2023d, ISO, 2017, S2Biom, 2017 and Wedistrict, 2021, S2Biom, 2017) The tool allows the user to modify the default values.

2.5 Database

A database has been created simulating each of the systems described in the section with different heating and cooling demand values and sizes for each technology. These simulations have been performed with the simulation tools developed throughout the project and based on the use of TRSNYS and JEPLUS (Zang, 2012). The database contains a total of 185640 simulations.

The WEDISTRICT tool extracts the energy flows for all technology size combinations based on user-selected localization and demand values from the database. It is necessary to use an interpolation process to obtain results corresponding to user's values of demand since the database is constructed from the discrete values.

2.6 Optimization

Firstly , the levelized cost of energy (LCOE) and the CO_2 emission factor (fCO_2) are calculated for each possible solution obtained from the database based on the input provided by the user. The CO_2 emission factor (fCO_2) is calculated by equation 5 (Ivančić et al., 2021).

$$\mathrm{fCO_2} = \frac{\sum k_{i,CO_2} \cdot E_i}{E_H + E_c} \tag{5}$$

Where k_{i,CO_2} is the emission factor of energy carrier i [kg CO_2/MWh], E_i is the energy supplied by energy carrier i [MWh], E_H is the annual heating energy supplied [MWh] and E_C is the annual cooling energy supplied [MWh]

The levelized cost of energy (LCOE) is calculated by equation 6 (Ivančić et al., 2021).

$$\mathrm{LCOE} = \frac{C_I \cdot CRF + C_{OM}}{E_H + E_c} \tag{6}$$

Where C_I is investment cost [€], CRF is the capital recovery factor [-], C_{OM} are the operation and maintenance costs [€], E_H is the annual heating energy supplied [MWh] and E_C is the annual cooling energy supplied [MWh]. The investment costs of piping are not included because they are difficult to

 https://doi.org/10.52202/077185-0104

estimate without having defined the final topology of the networks. The operation and maintenance cost include the fixed cost, the electricity costs and fuels costs.

Once the levelized cost of energy (LCOE) and CO2 emission factor (fCO2) are calculated, a set of optimal solutions are selected by assigning values (from 0 to 1) to the parameter w_1 of the objective function expressed by equation 7.

$$\min\ w_1 \cdot \frac{\mathrm{fCO_2}}{\mathrm{fCO}_{2,min}} + (1 - w_1) \cdot \frac{\mathrm{LCOE}}{\mathrm{LCOE}_{min}} \tag{7}$$

Where w_1 is a weighting factor [-], $\mathrm{fCO_2}$ is the CO_2 emission factor [kg CO_2/MWh], $\mathrm{fCO}_{2,min}$ is the minimum CO_2 emission factor [kg CO_2/MWh], LCOE is the levelized costs of energy [€/MWh] and LCOE_{min} is the minimum levelized costs of energy [€/MWh].

2.7 Results

Once the solutions obtained are selected, additional key parameters are calculated, and different graphs are represented. The key parameters calculated are the renewable energy ratio [%], non-renewable primary energy factor, gas share [%], solar share [%], CAPEX [€/MWh] and OPEX [€/MWh]. These parameters are calculated for the whole system and disaggregated into the contribution due to heating and cooling demand.

3 CASE STUDY

A case study has been conducted to demonstrate the capabilities of the WEDISTRICT tool. The district heating and cooling (DHC) system is situated in Rome (Italy), with an annual heating demand of 10 GWh/year and a cooling to heating demand ratio of 0.1 (1 GWh/year). A diagram of the system selected is presented in Figure 2.

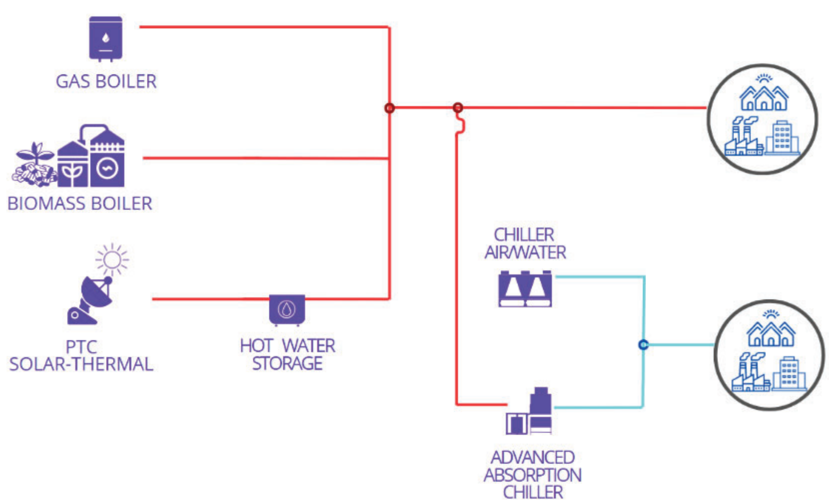

Figure 2: Layout of the district heating and cooling system studied.

Tables 5 and 6 list the economic and environmental data that are necessary for the simulation. In this instance, the tool's default values have been used.

https://doi.org/10.52202/077185-0104

Table 5: Economic data

Parameter	Value	Units
Discount rate	7	%
Lifetime	25	yr
Price electricity	185.3	€/MWh
Price biomass	20.93	€/MWh
Price Gas	40.2	€/MWh
Specific costs PTC	202.1	€/m^2
Specific costs TES	244.4	€/m^3
Specific costs biomass boiler	235	€/kW
Specific costs gas boiler	75.2	€/kW
Specific costs chiller A/W	184.24	€/kW
Specific costs AAC	564	€/kW
Fixed OM	3	%

Table 6: Emissions coefficients and primary energy factors for each energy carrier

Energy Carrier	Emission coefficients [kg CO_2/MWh]	Primary energy factor		
		Non renewable	Renewable	Total
Electricity	234	2.3	0.2	2.5
Gas	220	1.1	0	1.1
Biomass	40	0.2	1	1.2
Solar	0	0	1	1

The basic results provided by the WEDISTRICT tool are shown in Table 7. Case 1 has the minimum LCOE, while case 7 has the minimum emission factor. These results are represented in Figure 3. Additionally, Figure 4 illustrates the breakdown between CAPEX and OPEX of the LCOE. Case 1 has the lowest CAPEX, while case 5 has the lowest OPEX.

Table 7: Basic results.

Case	PTC Collector [m^2]	TES [m^3]	Biomass Boiler [kW]	Gas Boiler [kW]	Adv. Abs. Chiller [kW]	Chiller Air/Water [kW]	fCO_2 [kg/MWh]	LCOE [€/MWh]
1	1248	106	1775	1775	189	441	84.25	42.39
2	1248	106	2485	1065	126	441	82.12	42.49
3	2497	212	2485	1065	126	441	71.57	43.49
4	3746	318	2485	1065	126	441	62.99	44.90
5	3746	637	2485	1065	126	441	61.36	45.45
6	3746	955	2485	1065	126	441	61.08	46.24
7	3746	955	2485	1065	126	567	61.04	46.45

https://doi.org/10.52202/077185-0104

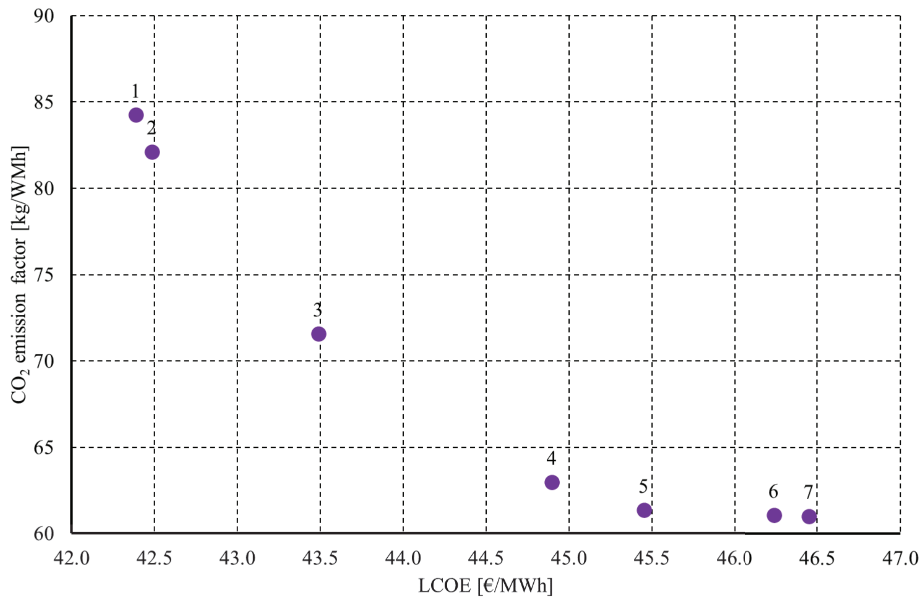

Figure 3: LCOE and emission factor for the optimal solutions.

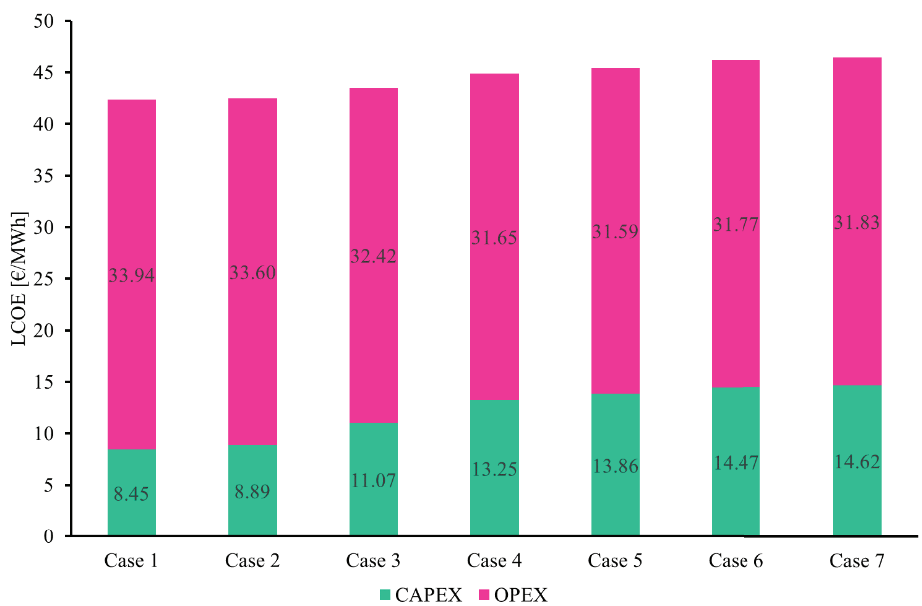

Figure 4: LCOE distinguishing between the contribution of CAPEX and OPEX for each of the optimal solutions.

The WEDISTRICT tool could provide additional results and graphics for the advanced user. Table 8 shows an example of the additional KPIs. This table includes the renewable energy coefficient, the non-renewable primary energy factor, the CO_2 emissions factor and the LCOE. The values corresponding to heating and cooling are distinguished for all key parameters. Case 7 has the minimum emissions for heating and cooling. However, case 1 has the minimum LCOE for heating but has the maximum LCOE for cooling. It is interesting to note case 2. This case presents the minimum LCOE for cooling and very low LCOE for heating.

https://doi.org/10.52202/077185-0104

Table 8: Advanced results.

Case	Heating renewable energy ratio [%]	Cooling renewable energy Ratio [%]	Heating non-renewable primary energy factor [-]	Cooling non-renewable primary energy factor[-]	Heating fCO_2 [kg/MWh]	Cooling fCO_2 [kg/MWh]	Heating LCOE [€/MWh]	Cooling LCOE [€/MWh]
1	69.50	41.84	0.39	1.10	78.68	142.61	32.81	142.88
2	69.77	35.98	0.39	1.03	77.88	126.19	34.34	127.14
3	73.64	37.63	0.34	1.00	66.91	120.00	35.31	128.46
4	76.74	39.05	0.30	0.97	58.04	114.41	36.77	129.34
5	77.42	39.30	0.29	0.97	56.32	113.79	37.31	130.04
6	77.56	39.35	0.29	0.97	56.01	113.77	38.11	130.71
7	77.56	39.19	0.29	0.96	56.01	112.10	37.91	133.31

In addition to Table 8, additional graphs are provided. For example, Figure 6 shows a detailed breakdown of LCOE. The cases with a highest LCOE have the solar field with the bigger area. In all cases, the OPEX due to biomass consumption is higher than that due to gas consumption.

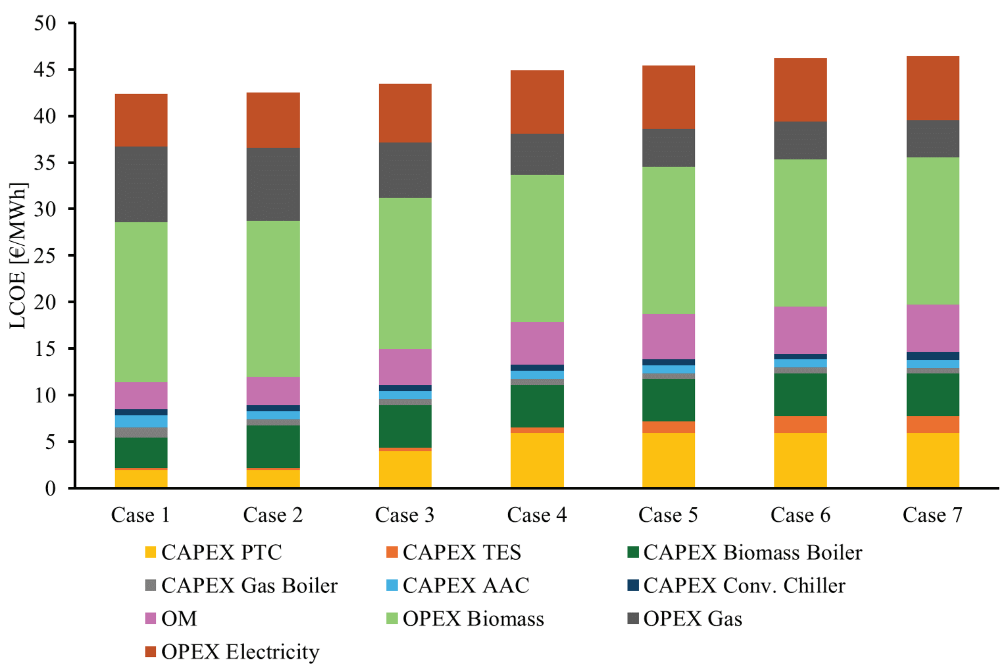

Figure 6. Detailed breakdown of LCOE.

The WEDISTRICT tool enables users to obtain detailed information about specific cases. As an example, Figures 7 and 8 corresponding to case 1 are presented. These figures represent the renewable energy ratio for both heating and cooling. Heating uses biomass as the primary energy source, whereas cooling relies on biomass and electricity.

https://doi.org/10.52202/077185-0104

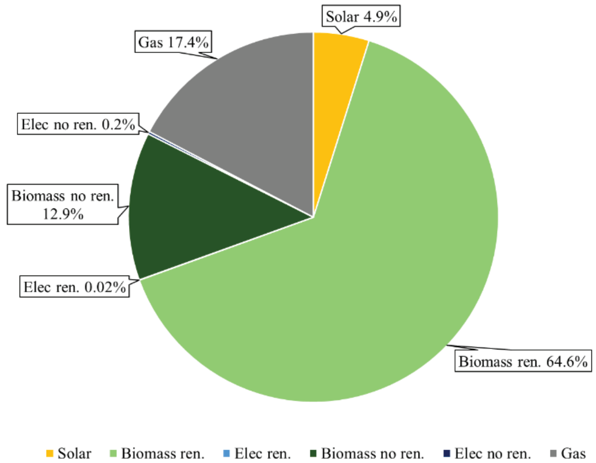

Figure 7. Renewable energy ratio for heating (case 1)**.**

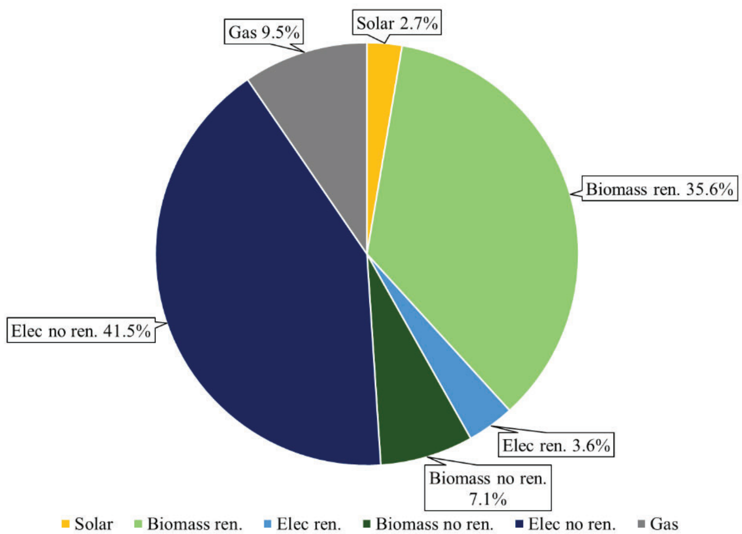

Figure 8. Renewable energy ratio for cooling (case 1).

Technology-based generation profiles are also available for both heating and cooling. The profiles of the case 1 are shown in Figure 9 and 10. As seen in the heating profile (Figure 9), biomass is the base load technology used throughout the year. During the winter, the demand is mainly covered by the biomass boiler, while the use of solar technology increases during the summer. In both cases, the gas boiler is the peak load technology. In both cases, the gas boiler is the peak load technology. In the profile corresponding to cooling, the absorption chiller is the base load technology while the compression chiller is the peak load technology.

https://doi.org/10.52202/077185-0104

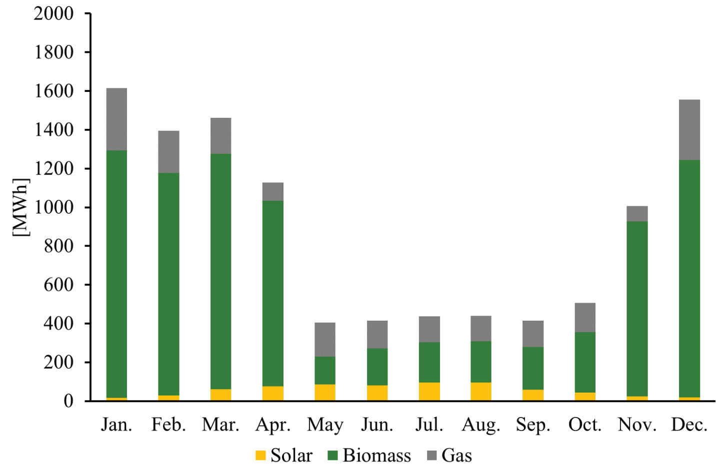

Figure 9. Heating monthly profile (case 1).

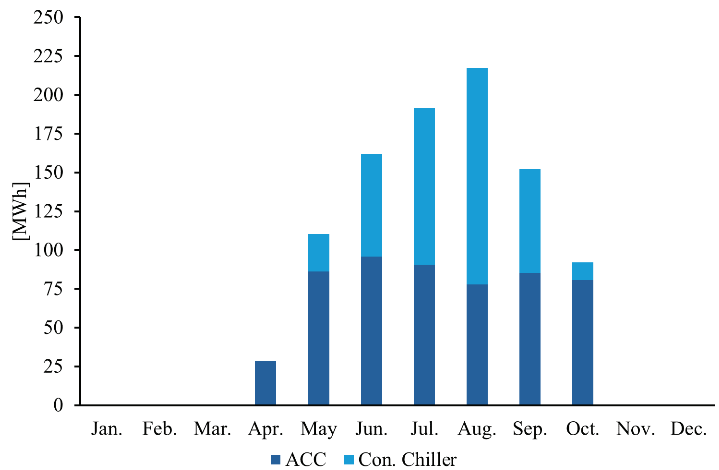

Figure 10. Cooling monthly profile (case 1).

4 CONCLUSIONS

This document presents the WEDISTRICT tool, which allows the preliminary assessment of a renewable district heating and cooling system. It illustrates the process of developing this software and the different assumptions made.

A case study has been carried out to demonstrate the functionality of the WEDISTRICT tool. The district heating and cooling network is located in Rome (Italy). The annual heating demand is 10 GWh, and the cooling demand is 1 GWh. The system consists of a parabolic trough collector field, a storage tank, a biomass boiler, and a gas boiler. An absorption and a compression chiller cover the cooling demands.

The results obtained through the tool make it possible to determine different optimal configurations from an environmental and economic point of view. In addition, the tool provides the user with a set of key parameters and advanced graphics that allow a detailed interpretation of the results. The main goal of this tool is to promote the knowledge, acceptance, and planning of heating and cooling networks

https://doi.org/10.52202/077185-0104

NOMENCLATURE

A_{SF} Area of the solar field [m^2]
c Scale Factor [-]
c_p Specific heat capacity of the water [k/(kg·K)]
$\overline{DNI}$ Average daily solar radiation available [kWh/m^2]
fCO_2 CO_2 emission factor [kg CO_2/MWh]
LCOE Levelized costs of energy [€/MWh]
$Q_{H,i}$ Hourly heating demand [kWh].
$Q_{C,i}$: Hourly cooling demand [kWh].
w_1 Weighting factor [-]
β Ratio between the annual heating and cooling demands [-]
ΔT Difference between the maximum and minimum water temperature [K]
η_{SF} Solar field efficiency [-]

REFERENCES

Allegrini, Jonas, et al. "A review of modelling approaches and tools for the simulation of district-scale energy systems." *Renewable and Sustainable Energy Reviews,* 52, 1391-1404.
EEA, 2021. Greenhouse Gas Emission Intensity of Electricity Generation.
EEA, 2022, Trends and projections in Europe 2022, EEA Report No 10/2022.
Eurostat 2023a. Heating and cooling from renewables gradually increasing.
Eurostat 2023b. Heating and cooling degree days – statistics
Eurostat 2023c. Energy consumption in households
Eurostat 2023d. Gas prices and electricity prices for non- household
Hotmaps. 2019. Available online: https://www.hotmaps-project.eu/ (accessed on 6 March 2024)
ISO, 2017, ISO 5200. Energy performance of buildings- Overarching EPB assessment.
Ivančić, A., et al, 2021 Performance Assessment of District Energy Systems with Common Elements for Heating and Cooling. *Energies* 14(8), 2334
Klein, S.A 20217, TRNSYS 18: A Transient System Simulation Program. Solar Energy Laboratory, University of Wisconsin, Madison, USA
Peel, M. C., Finlayson, B. L., and McMahon, T. A., 2007. Updated world map of the Köppen-Geiger climate classification. *Hydrology and earth system sciences*, 11(5), 1633-1644.
S2Biom, 2017. Tools for biomass chains.
Sartor, K., 2017. Simulation models to size and retrofit district heating systems. *Energies* 10.12
Stratego, 2016. Available online: https://heatroadmap.eu/sp_faq/heat-roadmap-europe-3-stratego-2015/ (accessed on 6 March 2024).
Törnros, Tobias, et al., 2016. "Geospatial Analysis of the Building Heat Demand and Distribution Losses in a District Heating Network" *ISPRS International Journal of Geo-Information 5*, 219
Wedistrict, 2021. D3.12 WEDISTRICT Technologies for DHCs. Available online: https://www.wedistrict.eu/wp-content/uploads/2021/07/WEDISTRICT_WP3_D3.12-WEDISTRICT-Technologies-for-DHCs.pdf
Zhang, Y., 2012, April. Use jEPlus as an efficient building design optimisation tool. In *CIBSE ASHRAE technical symposium*. Imperial College London.

ACKNOWLEDGEMENT

The work on this communication has been generated in the framework of the W.E.DISTRICT project, received funding from the European Union's Horizon 2020 research and innovation program under grant agreement N°857801.

https://doi.org/10.52202/077185-0104