SUPPLEMENTARY MATERIALS

Urban Sustainability: Recovering and Utilizing Urban Excess Heat

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The calculation Tool for comparison of costs of alternatives for heating

An excel-based calculation tool (here called as 'Tool') has been developed by ReUseHeat. The main objective of the Tool is to provide a way to test different assumptions impacting the cost of heating associated with different heating solution rather than to provide solid LCOH estimations. The Tool includes all relevant factors to compare LCOH of different heating solutions but also has several limitations and simplifications. The structure and contents of the tool are inspired by other, similar tools but adjusted to the specifics of the ReUseHeat project

The results obtained by applying that Tool compare the costs of different heat supply options in the three countries hosting the ReUseHeat demonstrators. The Tool calculates Levelized Cost of Heat (LCOH based on Equation S1:

$$LCOH = \frac{\sum_{t=0}^{T}\left(\frac{C\_Inv_t + C\_O\&M_t + C\_fuel_t + C\_tax_t + C\_env_t}{(1+r)^t}\right)}{\sum_{t=0}^{T}(MWh_t)} \quad \text{Eq.S1}$$

where C_Inv_t is the sum of all capital expenditures, $C\_O\&M_t$ is the sum of operational and maintenance costs, C_fuel_t is the cost of fuel, C_tax_t is the sum of all taxes paid and C_env_t is expenditures related to the environmental impact of the heating solution, all in year t. $(1+r)^t$ is the discount factor in year t with a discount rate r. MWh_t is the total amount of heat supplied to the household by a heating solution in year t. T is the number of years in the period studied.

The capital expenditures include both the investment cost (unit, installation, and commissioning) of the heating equipment (for the DH connection, the cost of the heat exchanger) and the cost of connecting the solution to the house. The operation and maintenance (O&M) costs include fixed and variable costs as well as the capacity fee.

The capacity fee reflects the cost for the DH provider carries for having the required capacity available for its consumer. The fuel cost for a) gas- and biomass-fired boilers is the price of gas and biomass, respectively; b) for electric heaters and heat pumps is the price of consumed electricity and c) for customers connected to high- and low-temperature DH is the cost of heating that the homeowner pays for the consumed heat. The environmental cost is the cost

for the emitted CO_2, i.e., the emission factor for the fuel, electricity or DH is multiplied by the price of CO_2 and the fuel consumed for generating the required heat.

Assumptions and inputs in the Tool

The assumptions and inputs included in the Tool can be categorised into three groups: a) general (relevant to all the technologies and all the countries); b) technology-specific; c) technology- and country-specific. All of the assumptions and inputs can be changed by the user.

General assumptions

The calculations are performed for a single-family house with an average yearly heating demand of 15 MWh. The capacity of the heat generation/supply unit (for the DH connections, the heat supply unit is the heat exchanger on the building side) is 20 kW. The investment year is 2020. The lifetime of the heat generation/supply units is 20 years. The discount rate is 5%. The price of CO_2 emissions is assumed to increase from around 30 €/tCO_2 in 2020 to around 125 €/tCO_2 in 2040 (corresponding to the WEO (World Energy Outlook) estimates for "advanced economies" in the Sustainable Development scenario [S1].

Technology-specific assumptions

The technology-specific parameters that, in this study, differ among the investigated individual heating solutions but are assumed to have identical values for each investigated country are as follows: investment cost (€/kW), fixed O&M cost (€/yr), variable O&M cost (€/kWh), energy conversion efficiency, and CO_2 emissions factors for biomass, natural gas, oil (tCO_2/kWh of fuel).The values for these parameters assumed in this study are mainly based on the information available in the Danish Technology Catalogue [S2] but were also updated based on the data in other sources [S3].

Technology- and country-specific assumptions

The technology- and country-specific parameters included in the LCOH calculations are as follows: fuel/electricity/heat price (€/kWh), capacity fee (€/kW), VAT (€/kWh), other taxes and levies (€/kWh), yearly average CO_2 emissions factors of electricity generation applied to electric boilers and heat pumps, CO_2 emissions factors of DH-supplied heat (tCO_2/kWh of fuel), and investment, fixed, and variable O&M costs for the high- and low-temperature DH connections. The values for these parameters were checked and updated by the ReUseHeat partners in each demonstration site country. The yearly average CO_2 emissions factors of electricity generation in the investigated countries were taken from the dataset compiled by the European Environment Agency [S4]. The average CO_2 emission factor of heat generation in the DH systems in Germany [S5] was assumed identical in Spain and France. All of the inputs together with the different heating solution are shown in Tables S2, S3 and S4. Figures S3 – S5 present the results of the calculations.

Table S1. Excess heat source types, recovery types, temperature ranges, temporality and the HP conversion type for the investigated heat sources.

Excess heat source type	Source of excess heat recovery	Temperature range ºC	Seasonal temporality	Heat pump conversion
Data centers	Server room air cooling systems	25 - 35	Principally constant	Air to water
Metro stations	Platform ventilation exhaust air	5 - 35	Variable	Air to water
Waste-water treatment plants	Post-treatment sewage water	8 - 15	Principally constant	Water to water
Service sector buildings	Central cooling device	30 - 40	Variable	Liquid to water
Residential sector buildings	Central cooling device	30 - 40	Variable	Liquid to water
Food production facilities	Rejected heat from refrigeration processes	20 - 40	Principally constant	Liquid to water
Food retail stores	Rejected heat from refrigeration processes	40 - 70	Principally constant	---

Table S2. The techno-economic parameters assumed for the LCOH calculation of the individual and DH technologies - Germany.

GERMANY	Unit	Gas boiler	Biomass boiler	Oil boiler	Electric boiler	Air-to-water HP	Brine-to-water HP	High-temp DH	Low-temp DH
Unit size	kW	20	20	20	20	20	20	20	20
Investment year	-	2020	2020	2020	2020	2020	2020	2020	2020
Single unit ivestment	EUR	6440	10740	7515	4965	12485	20000	5320	5320
Single unit fix O&M cost	EUR/yr	255	605	295	65	360	360	80	80
Connection cost	EUR/kW	0	0	0	0	0	0	270	270*
Var. O&M	EUR/MWh	1	1	1	1	1	1	4	4
Fuel /electricity /DH price	EUR/MWh_fuel	43	48	46	150	150	150	50	40
Capacity fee	EUR/kW	6	0	0	0	0	0	11.95	11.95
VAT	EUR/MWh_fuel	9	3	10	50	50	50	10	10
Taxes and levies (excl. VAT)	EUR/MWh_fuel	11	0	6	115	115	115	0	0
Fixed O&M	EUR/kW	12.8	30.3	14.8	3.3	18	18	4	4
Total efficiency		0.92	0.8	0.92	1	2.89	4.09	0.95	0.95
Lifetime	years	20	20	20	20	20	20	20	20
Emission factor	$kgCO_2$/MWh_fuel	204	0	285	311	311	311	100	50

* The connection to a low-temperature DH network might be a bit higher compared to the cost of the high-temperature DH connection as there is a higher investment in the infrastructure necessary (larger pipe diameters, etc.). However, this was not considered in our analysis due to the lack of data.

The input data for the calculation of the levelized cost of heat (LCOH) in Germany can be found in Supporting references [S6-S13].

Table S3. The techno-economic parameters assumed for the LCOH calculation of the individual and DH technologies – Spain.

SPAIN	Unit	Gas boiler	Biomass boiler	Oil boiler	Electric boiler	Air-to-water HP	Brine-to-water HP	High-temp DH	Low-temp DH
Unit size	kW	20	20	20	20	20	20	20	20
Investment year	-	2020	2020	2020	2020	2020	2020	2020	2020
Single unit investment	EUR	6440	10740	7515	4965	12485	20000	6175	6175
Single unit fix O&M cost	EUR/yr	255	605	295	65	360	360	65	65
Connection cost	EUR/kW	0	0	0	0	0	0	200	200*
Var. O&M	EUR/MWh	1	1	1	1	1	1	1	1
Fuel /electricity /DH price	EUR/MWh_fuel	52	45	81	133	133	133	59	47
Capacity fee	EUR/kW	0	0	0	0	0	0	0	0
VAT	EUR/MWh_fuel	11	9	17	40	40	40	12	10
Supporting references (excl. VAT)	EUR/MWh_fuel	2.3	0	2.3	60	60	60	0	0
Fixed O&M	EUR/kW	12.8	30.3	14.8	3.3	18	18	3.3	3.3
Total efficiency		0.92	0.8	0.92	1	2.33	2.63	0.95	0.95
Lifetime	years	20	20	20	20	20	20	20	20
Emission factor	$kgCO_2$/MWh_fuel	204	0	285	156	156	156	100	50

* The connection to a low-temperature DH network might be a bit higher compared to the cost of the high-temperature DH connection as there is a higher investment in the infrastructure necessary (larger pipe diameters, etc.). However, this was not considered in our analysis due to the lack of data.

Sources of the input data for the calculation of the levelized cost of heat (LCOH) in Spain are included in Supporting references [S12-S16].

Table S4. The techno-economic parameters assumed for the LCOH calculation of the individual and DH technologies – France.

FRANCE	Unit	Gas boiler	Biomass boiler	Oil boiler	Electric boiler	Air-to-water HP	Brine-to-water HP	High-temp DH	Low-temp DH
Unit size	kW	20	20	20	20	20	20	20	20
Investment year	-	2020	2020	2020	2020	2020	2020	2020	2020
Single unit investment	EUR	6440	10740	7515	4965	12485	20000	-	-
Single unit fix O&M cost	EUR/yr	255	605	295	65	360	360	-	-
Connection cost	EUR/kW	0	0	0	0	0	0	240	240*
Var. O&M	EUR/MWh	1	1	1	1	1	1	18	18
Fuel /electricity /DH price	EUR/MWh_fuel	47	45	78	126	126	126	55	44
Capacity fee	EUR/kW	0	0	0	0	0	0	35	35
VAT	EUR/MWh_fuel	9	3	15	26	26	26	10.45	8.4
Taxes and levies (excl. VAT)	EUR/MWh_fuel	10	0	2	40	40	40	0	0
Fixed O&M	EUR/kW	12.8	30.3	14.8	3.3	18	18	0	0
Total efficiency		0.92	0.8	0.92	1	2.89	4.09	0.95	0.95
Lifetime	Years	20	20	20	20	20	20	20	20
Emission factor	$kgCO_2$/MWh_fuel	204	0	285	51	51	51	100	50

* The connection to a low-temperature DH network might be a bit higher compared to the cost of the high-temperature DH connection as there is a higher investment in the infrastructure necessary (larger pipe diameters, etc.). However, this was not considered in our analysis due to the lack of data.

Sources of the input data for the calculation of the levelized cost of heat (LCOH) in France are included in Supporting references [S12-13, S17].

Table S5. Sources of urban excess heat, number of source units within the distance of two kilometers from a DHN and energy data (in the unit of PJ/year).

Source of excess heat recovery	Number of units	Accessible heat
Data centers	985	269.4
Metro stations	1 767	27.7
Food production	554	3.7
Food retail	16 833	49.9
Buildings – service sector	[1]	221.4
Buildings – residential sector	[1]	103.5
Sewage water (waste-water treatment plants)	2 617	497.7
Total		1173.3

[1] based on cooling demand of the building stock

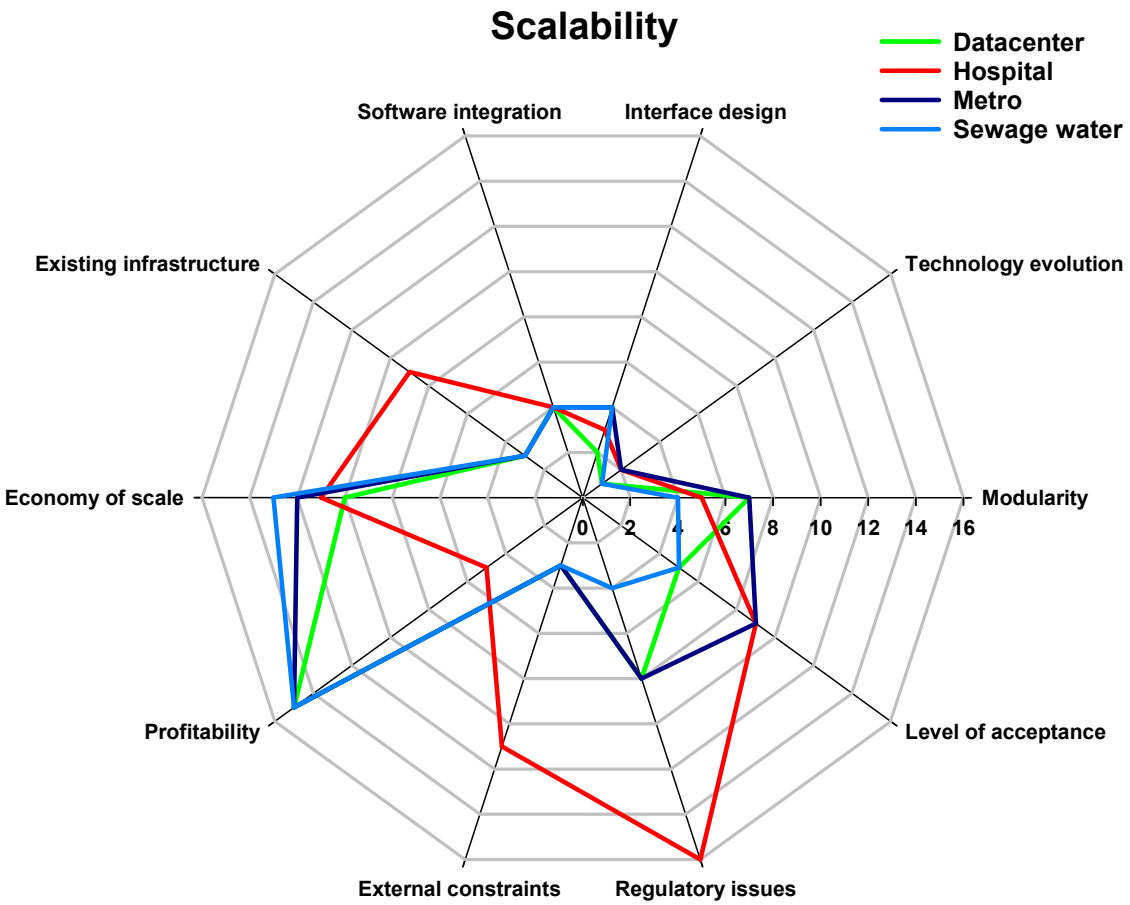

Figure S1. Computed Scalability factors.

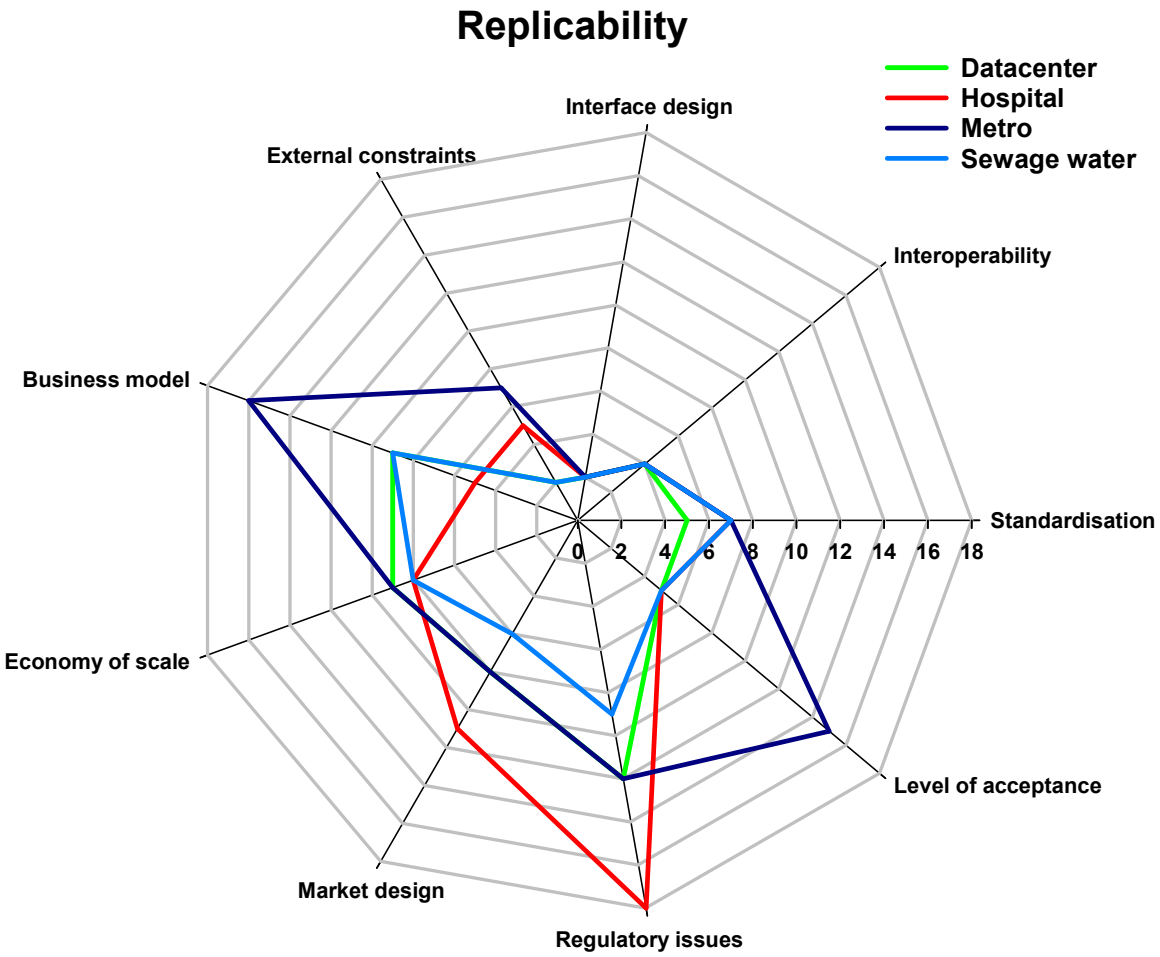

Figure S2. Computed Replicability factors.

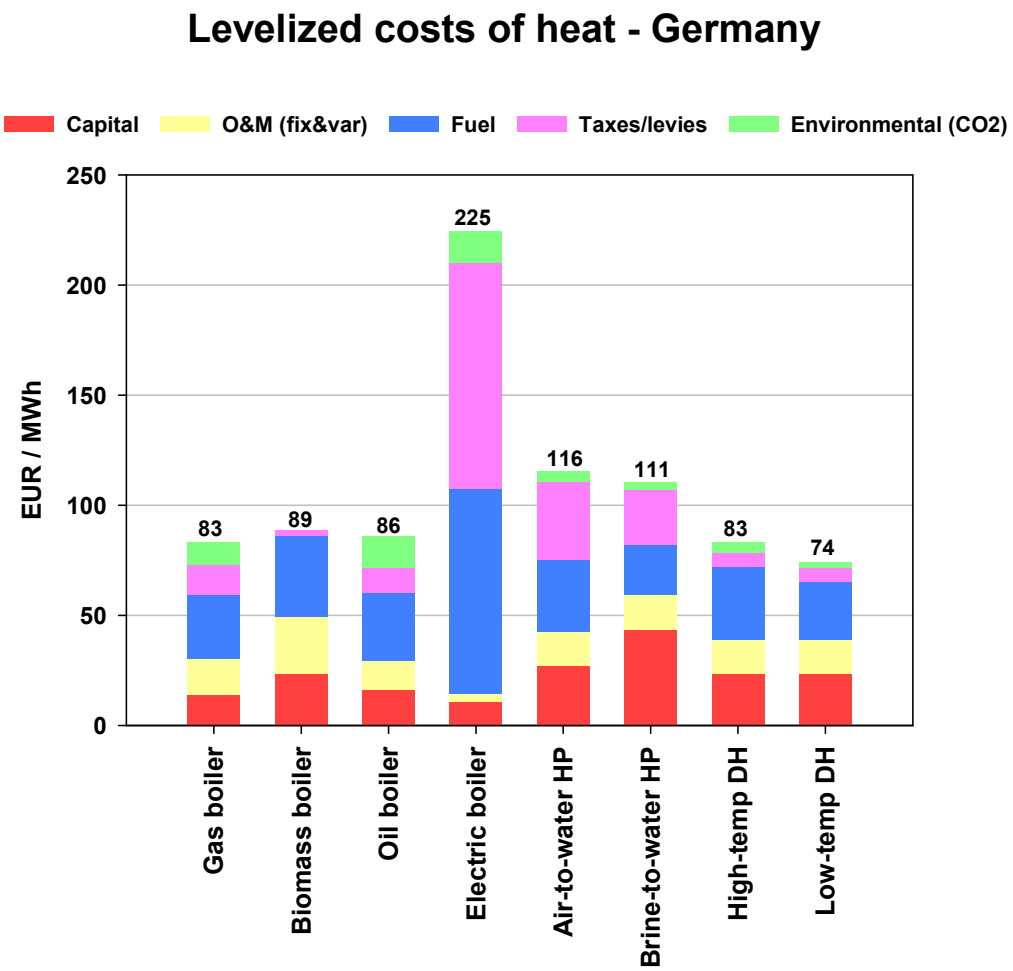

Figure S3. The LCOH estimations for the analysed heat supply options for Germany.

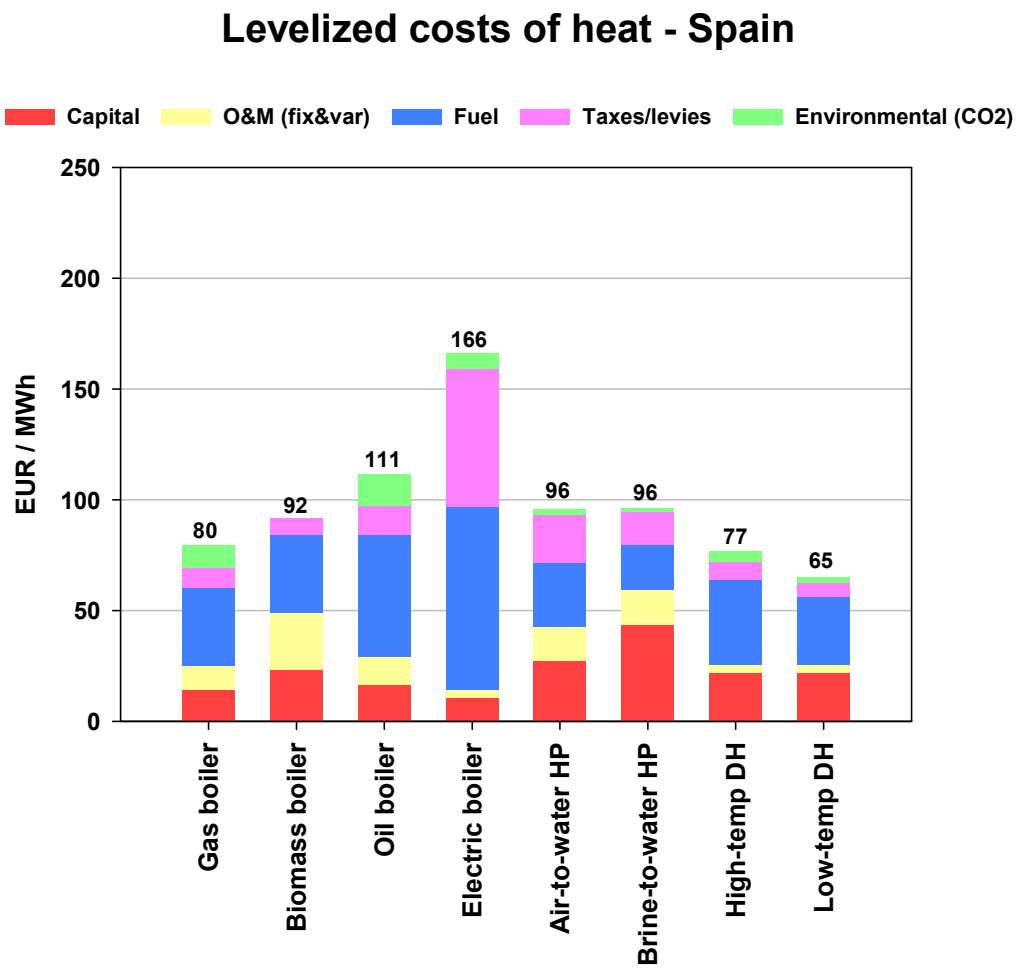

Figure S4. The LCOH estimations for the analysed heat supply options for Spain.

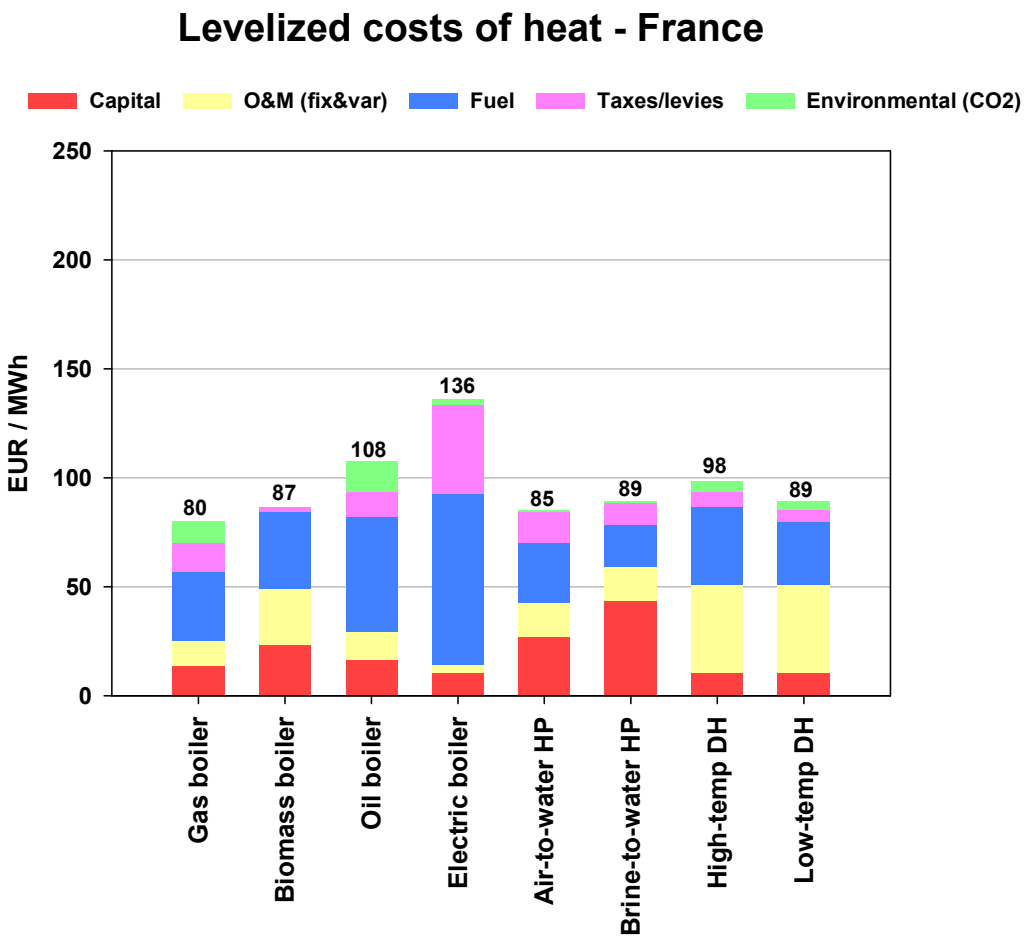

Figure S5. The LCOH estimations for the analysed heat supply options for France.

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