Evaluated and approved blueprints for improved economic analyses

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Executive summary

This document presents and summarises the economic analysis blueprints developed in **Deliverable 4.1** of the **LIFE21 GeoBOOST project**. The blueprints define a standardised framework to compare geothermal heat pump (GHP) systems with other heating and cooling options.

At their core is a life-cycle cost (LCC) methodology and associated Excel-based tool with country-specific presets for all GeoBOOST partner countries. The approach is designed to capture the specific features of GHP systems, such as their dual operation (heating and cooling) and long asset lifetimes. These characteristics are reflected in the methodology through residual value calculations and component-level replacements over the analysis period. Using these blueprints, users can evaluate representative GHP utilisation concepts and non-GHP alternatives (air-source heat pumps, heat-only boilers and district heating) for different cases that reflect current European markets. The tool reports the net present value (NPV) of total costs and the levelised cost of energy (LCOE). In this manner, GHP systems with higher upfront investment but lower running costs can be compared fairly with alternatives that are cheaper to install but less efficient over their lifetime.

This document explains what the blueprints contain, how the LCC workflow is organised, and how the Excel tool and presets can be used. It also illustrates the approach with example results from the portfolio. It constitutes Milestone 6 in Work Package 4 (WP4).

1. Context and objectives

Deliverable 4.1 of the GeoBOOST project responds to the need for a standardised economic evaluation framework that can clearly demonstrate the financial value of geothermal heat pump (GHP) technologies to end-users, investors and decision-makers. Although GHP systems are well recognised for their energy efficiency and long technical lifetimes, their comparatively high upfront capital expenditure often remains a barrier to wider adoption. In addition, economic assessments are frequently carried out with different tools, assumptions and time horizons, which makes results difficult to compare across projects and countries.

This was addressed by applying economic evaluation schemes to a cross-cut of representative GHP systems and relevant alternatives. Building on inputs from WP2 and WP5, it defines a portfolio of cases that reflects current European market conditions and applies a consistent LCC approach to compare the total cost of these options over time.

The purpose of this document, designated as **Milestone 6**, is to summarise the economic-analysis blueprints developed in Deliverable 4.1, explain how they are used, and demonstrate their suitability for supporting comparable techno-economic assessments of GHP systems across different European contexts. It is intended for project partners and external stakeholders who need transparent, like-for-like cost comparisons when assessing GHP investments.

Validation by the Advisory Committee. A previous version of this document was submitted to the GeoBOOST Advisory Committee for review.

2. Blueprint definition

In the context of GeoBOOST, the economic-analysis blueprints define how techno-economic assessments of GHP systems and their main alternatives should be carried out and presented. They include the methodology and its implementation:

i. **LCC methodology**
A LCC framework based on established principles, adapted to capture the distinctive economic characteristics of GHP systems. It sets common rules for the analysis period, discounting rate, treatment of renewals and residual values, and defines NPV of costs and LCOE as the core metrics. The methodology is aligned with international cost-management practice while incorporating GHP-specific aspects such as long-lived ground infrastructure and the option to account for CO_2 emissions from the operational point of view.

ii. **Excel-based LCC tool**
An implementation of the methodology delivered as an Excel-based LCC assessment tool, that includes:
- structured input sheets with pre-configured country presets and size classes;
- automated calculation of NPV and LCOE;
- side-by-side comparison of GHP systems with air-source heat pumps, heat-only boilers and district heating;
- visual outputs, such as cost-breakdown charts and NPV-over-time curves, for interpretation and reporting.

Hence, these two components form the blueprint package: they specify how inputs should be defined, how costs are calculated and discounted, and how results are presented so that assessments are consistent and comparable across cases and countries.

3. The LCC methodology

The LCC analysis methodology accounts for all significant costs throughout the entire lifespan of heating and cooling systems. The methodology divides costs into key categories based on when they occur: Acquisition Costs (AC), Construction Costs (CC), Renewal Costs (RC), Operation Costs (OC), Maintenance Costs (MC), and End-of-Life Costs (EC).

3.1. Special aspects of GHP systems

Asset lifetime and residual value
GHP systems combine components with very different technical lifetimes. In closed-loop systems, the underground infrastructure is typically designed for a very long service life, often several decades. With correct design and installation, it can last around 100 years. In open-loop systems, abstraction and reinjection wells usually have shorter design lifetimes, as their performance is more strongly influenced by groundwater quality. Even so, the subsurface infrastructure in both concepts normally lasts longer than the heat pump unit itself. The heat pump and associated utility room equipment are typically assumed to operate for about 20 – 25 years, which is somewhat longer than for most air-source heat pumps (around 15 years). This is because GHPs are installed indoors and operate under more stable thermal conditions, avoiding exposure to weather and temperature extremes.

The methodology reflects these different lifetimes explicitly. Each major component (borehole field, wells, heat pump unit) is assigned its own technical life. Costs are spread over the technical life using straight-line depreciation, and any remaining value at the end of the analysis period is treated as a residual value. For example, if the analysis covers 25 years, the model accounts for the remaining value of long-lived subsurface infrastructure (borehole fields and wells) at year 25. Part of the plant room equipment also retains value. This is particularly important for GHP systems, where a substantial share of the upfront investment remains useful beyond the typical 20 – 30 year horizon used in economic studies.

Operational CO_2 emissions tracking

In addition to financial metrics, the methodology tracks operational CO_2 emissions for all technologies. The results sheet reports annual and cumulative emissions (tonnes CO_2-eq) alongside bought energy, and distinguishes between fossil and biogenic emissions where relevant (e.g. wood-pellet boilers). This enables a direct comparison of environmental performance alongside cost-based indicators. Emission factors are user-defined, so they can be adjusted to reflect national inventories, project-specific data or changes in grid carbon intensity over time. Where required, a carbon price (EUR/tonne CO_2-eq) can also be applied so that the cost of emissions is reflected in the LCC results.

3.2. Country-specific presets

To facilitate application across diverse European contexts, the tool incorporates country-specific presets covering all GeoBOOST partner countries: Austria, Germany, Ireland, the Netherlands, Poland, Spain, and Sweden. In addition, a preset for France has been included. Each preset takes into account:

- **Climate conditions**: Heating and cooling degree days, affecting energy demand and heat pump performance ratings per EN14825 standard;
- **Geological characteristics**: Ground thermal properties influencing borehole field design and sizing;
- **Cost structures**: National variations in drilling costs (taken from Deliverable 2.1), equipment prices, labour rates, and energy tariffs;
- **System design assumptions**: Borehole field sizing derived from Earth Energy Designer (EED) simulations tailored to each country's thermal loads and ground conditions.

These presets provide realistic starting points for analysis while remaining customisable for project-specific circumstances.

3.3. Economic metrics: NPV and LCOE

Net Present Value (NPV)

NPV expresses the total LCC of a system in today's money. All future costs (investment, operation, maintenance, renewals, end-of-life, minus residual value) are discounted back to the present. A lower NPV means the technology is cheaper over the analysis period. A higher NPV means it is more expensive overall.

Levelised Cost of Energy (LCOE)

LCOE expresses the average cost of delivered energy over the life of the system, in EUR/MWh. It is obtained by dividing the discounted total costs by the total energy supplied. A lower LCOE means cheaper energy per MWh, and is therefore economically more attractive when comparing technologies.

4. The Excel LCC tool

The Excel-based LCC tool implements the methodology in two main worksheets: an "*LCC Inputs*" sheet and a "*Results*" sheet. The tool automatically performs all necessary calculations, presents the results visually, and enables sensitivity analysis. The figure on the next page illustrates how the "*LCC Inputs*" sheet of the Excel-based LCC tool looks like.

4.1. Comparator technologies

The tool aims to evaluate GHP systems against the main technology alternatives:

- **Air-source heat pumps (ASHP):** Accounting for climate-dependent performance and shorter equipment lifespans;
- **Heat-only boilers (HOB):** Adaptable for different fuel types, including natural gas, heating oil and biomass;
- **District Heating (DH):** With adjustable connection costs.

Additionally, the tool incorporates provisions for evaluating complementary cooling services, given that reversible heat pumps can provide both heating and cooling. The tool thus builds upon the technological portfolio developed in **Deliverable 5.1** and **Milestone 5**.

4.2. Minimum input requirements

The tool minimises user burden by including default values, with the possibility to overwrite them, when more specific data is available. The following project-specific inputs are required:

- **System sizing:** Installed peak capacity (kW), with automatic estimation of annual heating and cooling energy demands based on country preset;
- **Supply temperature:** The user can select between two options: 35 °C and 55 °C, which influence heat pump performance;
- **Analysis parameters**: Period of analysis and discount rate;
- **Country selection**: Automatically populates climate data, costs, and performance assumptions;
- **Fuel costs**: Suggestions are provided, but it is up to the user to decide the final values to be used for the calculations;
- **Share of self-generated electricity:** The % of electricity generated on site and not bought from the grid.

LCC Inputs

Country	Sweden

System Size Parameters			Override:	
Heating				
Installed Capacity	100	kW		
Heating Delivered SH	388	MWh/yr		MWh/yr
DHW	103	MWh/yr		MWh/yr
Supply Temperature of heating system	55	˚C		
Cooling				
Peak Demand	59	kW		kW
Cooling Delivered	11	MWh/yr		MWh/yr

Standard LCC Parameters			Override:	
Period of analysis	25	Years		
Inflation (e)	2	%		
Discount (i)	5.5	%		
Real discount rate (r)	3.43	%	3.50	%
WACC Calculator				
Portion of Equity (Pe)	50	%		
Portion of Debt (Pd)	50	%		
Total Cost of Debt (Rd)	4	%		
Tax rate (Td)	25	%		
Total Cost of Equity (Re)	5.5	%		
WACC (r)	4.25	%		

Fuel Costs			Override:	
Electricity	0.243	EUR/kWh		EUR/kWh
District Heating	0.102	EUR/kWh		
Pellets	0.092	EUR/kWh		
Natural Gas	0.176	EUR/kWh		
Oil	0.121	EUR/kWh		
Coal	-	EUR/kWh		
Share of self-generated electricity	0	%		

District Heating Solution			Override:	
Physical Life Heat Exchanger:	30	Years		
CAPEX				
Heat exchanger/Central:	20090	EUR		EUR
Connection to network:	18860	EUR		EUR
Installation:	2050	EUR		EUR
Total Costs:	41000	EUR		EUR
OPEX				
Regular Service/Maintenence:	137.5	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	1025	EUR		EUR
Renewal				
Heat exchanger/Central:	20090	EUR		EUR
Installation:	2050	EUR		EUR

HO Boiler solution			Override:	
Physical Life Boiler:	15	Years		
CAPEX				
Boiler:	330	EUR/kW		
Boiler:	33000	EUR		EUR
Installation:	11913.5	EUR		EUR
Total Costs:	44913.5	EUR		EUR
OPEX				
Boiler efficiency	0.95	-		
Fuel Cost	0.092	EUR/kWh		
Regular Service/Maintenence:	1046	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	5956.75	EUR		EUR
Renewal				
Installation:	11913.5	EUR		EUR
Boiler	33000	EUR		EUR

Complementary Cooling Solution			Override:	
Physical Life:	15	Years		
CAPEX				
Cooling components cost:	24780	EUR		EUR
Installation:	1218.75	EUR		EUR
Total Costs:	25998.75	EUR		EUR
OPEX				
SEER	8	-		
Regular Service/Maintenence:	406.25	EUR/yr		EUR
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	609.375	EUR		EUR
Renewal				
Installation:	1218.75	EUR		EUR
Cooling components cost:	24780	EUR		EUR

Fuel Emissions Factors			Override:	
Electricity	8	g CO2-eq/kWh		g CO2-eq/kWh
District Heating	50	g CO2-eq/kWh		
Wood Pellets	5	g CO2-eq/kWh		g CO2-eq/kWh
Wood Pellets (Biogenic CO2)	349	g CO2-eq/kWh		g CO2-eq/kWh
Natural Gas	240	g CO2-eq/kWh		g CO2-eq/kWh
Oil	306	g CO2-eq/kWh		g CO2-eq/kWh
Coal	363	g CO2-eq/kWh		g CO2-eq/kWh

Cost of CO2 Emissions		
Include Cost in LLC?	Yes	
Cost of CO2 Emissions:	60	EUR/ ton CO2-eq
Type of Heat Only Boiler:	Wood (Pellets)	

GSHP-Specific Parameters Closed Loop System			Override:	
Physical Life Heat Pump:	20	Years		
Physical Life Boreholes:	100	Years		
CAPEX				
Borehole field				
Thermal Conductivity (Lambda):	3	W/(mK)		
Total Drilling Depth:	4053	m		
Cost of drilling and collectors:	31	EUR/m		
Cost of drilling and collectors:	125656	EUR		EUR
Digging/Horizontal piping:	53852	EUR		EUR
Pre-studies and dimensioning:	7000	EUR		EUR
Permits:	500	EUR		EUR
Total Cost:	187008	EUR		EUR
Building/Utility Room				
Heat Pump:	454	EUR/kW		
Heat Pump:	45428.6	EUR		EUR
Heat Pump Installation:	1188	EUR		EUR
Passive Cooling:	2860	EUR		EUR
Active Cooling:		EUR		
Total Cost:	49476	EUR		EUR
OPEX				
SCOP SH:	4	-		-
SCOP DHW:	3	-		-
SEER:	20	-		
Regular Service/Maintenence:	220	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning HP:	1188	EUR		EUR
Renewal				
Heat Pump:	45428.6	EUR		EUR
Installation:	1188	EUR		EUR

GSHP-Specific Parameters Open Loop			Override:	
Physical Life Heat Pumps:	20	Years		
Physical Life Boreholes:	40	Years		
CAPEX				
Borehole field				
Cost of drilling and collectors:	62828	EUR		EUR
Digging/Horizontal piping:	26926	EUR		EUR
Pre-studies and dimensioning:	8000	EUR		EUR
Permits:	500	EUR		EUR
Total Cost:	98254	EUR		EUR
Building/Utility Room				
Heat Pump:	454	EUR/kW		
Heat Pump:	45428.6	EUR		EUR
Heat Pump Installation:	1187.5	EUR		EUR
Cooling:	2860	EUR		EUR
Total Cost:	49476.1	EUR		EUR
OPEX				
SCOP SH:	4	-		-
SCOP DHW:	3	-		-
SEER:	20	-		
Regular Service/Maintenence:	440	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	593.75	EUR		EUR
Renewal				
Installation:	1187.5	EUR		EUR
Heat Pump:	45428.6	EUR		EUR

Air Source Heat Pump Solution			Override:	
Physical Life Heat Pump:	15	Years		
CAPEX				
Heat Pump:	566	EUR/kW		
Heat Pump:	56617.6	EUR		EUR
Heat Pump Installation:	2214.06	EUR		EUR
Active Cooling:	2860	EUR		EUR
Total Cost:	61691.7	EUR		EUR
OPEX				
SCOP SH:	3	-		-
SCOP DHW:	3	-		-
SEER:	6.2	-		-
Regular Service/Maintenence:	601.563	EUR/yr		EUR/yr
Interval of major repairs:	0	Years		
Average cost major repair:	0	EUR		
Decomissioning/Renewal				
Decomissioning:	1107	EUR		EUR
Renewal				
Installation:	2214.06	EUR		EUR
Heat Pump:	56617.6	EUR		EUR

4.3. Use cases

The tool's design explicitly supports multiple use cases. For example:

Pre-feasibility assessment
Rapid comparison of different system capacities to identify optimal sizing, useful during early project planning when detailed specifications are not yet available.

Sensitivity analysis
Systematic evaluation of how results vary with different parameters:

- Discount rates (financial perspective impacts);
- Electricity and fuel price scenarios;
- Drilling costs (addressing geological uncertainty);
- Supply temperature;
- Seasonal performance factors for heat pumps.

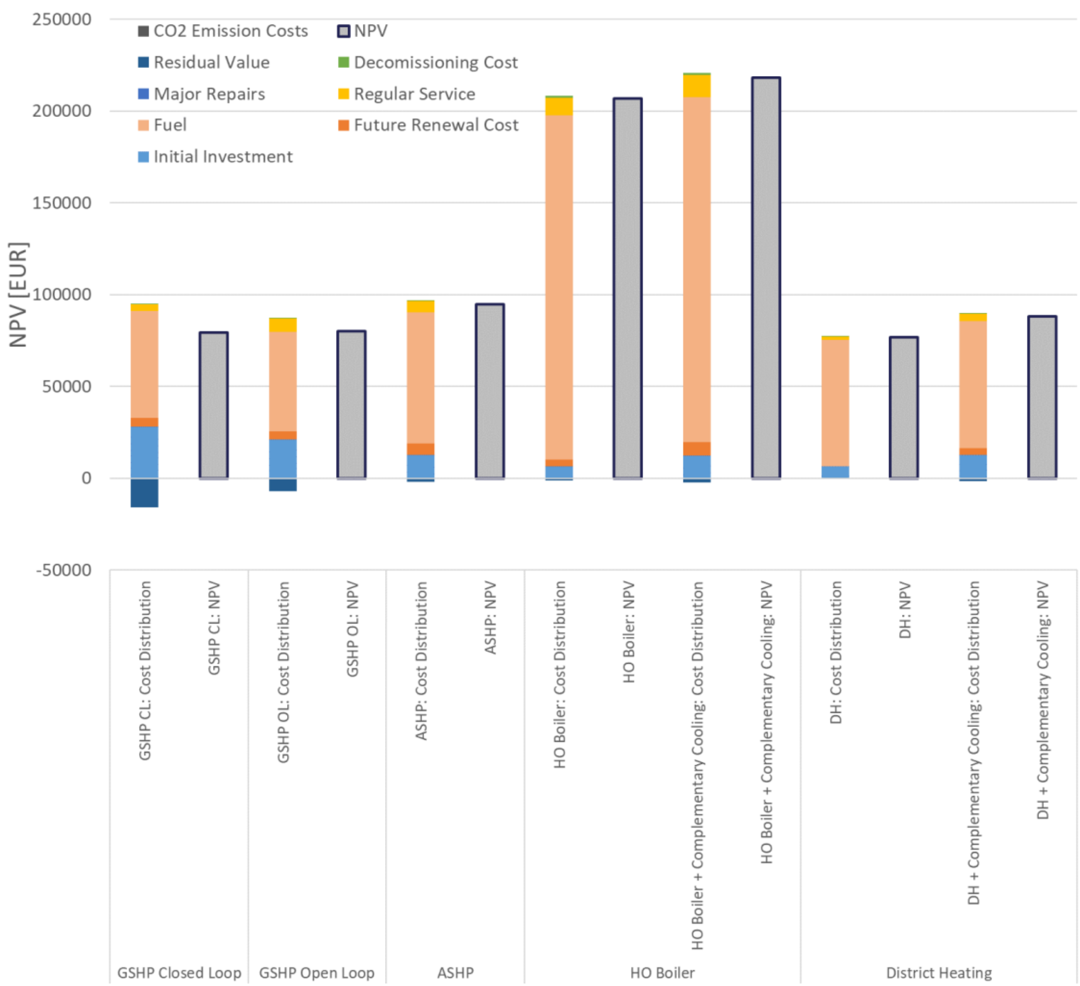
These analyses can show how robust the GHP option is under different assumptions and which parameters matter most for the decision.

4.4. Illustrative results

The table below provides illustrative results for a residential application in Sweden, considering as inputs 10 kW heating capacity, 25-year analysis period, 55 °C supply temperature, and 3.5% discount rate. Further calculation examples are available in Deliverable 4.1. Note that the HOB (gas considered in this case) and DH have been costed by adding a complementary cooling module sized to the GHP's cooling duty.

Technology	CAPEX (EUR)	OPEX (EUR)	Residual value (EUR)	NET CAPEX (EUR)	NPV for 25 years (EUR)	LCOE (EUR/MWh)
GHP (closed loop)	28,154	67,012	-15,813	12,341	79,353	96
GHP (open loop)	21,120	66,028	-6,962	14,158	80,185	97
ASHP	12,856	83,957	-2,041	10,816	94,772	115
HOB (gas)	12,384	208,168	-2,464	9,920	218,088	264
DH	12,620	77,081	-1,734	10,886	87,967	106

The tool's output visualisations include cost allocation breakdowns (see exemplary figure below) and NPV progression charts that communicate the economic trade-offs between high-CAPEX/low-OPEX GHP solutions and lower initial cost alternatives. In fact, this figure illustrates such a classic trade-off: the GHP options have the highest initial investment (partly offset by the residual value), but the lowest 25-year NPV because lifetime costs are driven far less by fuel expenditure. In contrast, the HOB's NPV is dominated by fuel costs, and adding complementary cooling pushes total lifetime cost even higher, leaving the boiler option markedly above the heat-pump and DH cases.



5. Usability and accessibility features of the tool

The Excel tool has been prepared with accessibility in mind, anticipating that users will have varying levels of technical expertise and diverse application requirements. The main usability features are:

- **Visual hierarchy:** Input cells are colour-coded to distinguish user-editable parameters (dark grey) from automatically calculated values (light red), preventing inadvertent modification of formulas;
- **Dropdown selections:** Country presets and standard options are accessible through dropdowns to minimise data entry errors;
- **Organised input structure:** Parameters are grouped logically by category (system sizing, financial parameters, technology-specific inputs);
- **Automatic calculations**: Energy demands, performance factors, and costs update instantly as inputs are modified;

- **Outputs**: Results sheet presents NPV, LCOE, cost breakdowns, and graphical comparisons.

Deliverable 4.1 provides a detailed guidance on tool operation, interpretation of results, and best practices for conducting comparative analyses.

6. Known limitations

While the blueprints provide a robust framework for economic analysis, it is important to acknowledge inherent limitations and opportunities for future improvements:

- **Simplified energy modelling:** The tool estimates energy demands based on installed capacity and climate data but does not perform detailed building energy simulations. This is sufficient for pre-feasibility studies as intended, however for detailed planning with precise load profiles, specialised software should be used to determine inputs;
- **Country-level aggregation:** Country presets represent national averages, whereas actual costs and conditions may vary significantly within countries. Regional customisation is recommended for site-specific analyses;
- **Non-energy benefits:** Other possible advantages of GHPs, such as improved thermal comfort, reduced noise (compared to ASHP), enhanced property value and reliable operation, are currently not monetised in the NPV/LCOE calculations;
- **Residential load profile:** Country presets are calibrated to typical residential demand profiles, where climate-driven space-heating and cooling needs dominate, even though occupancy patterns also play a role. For non-residential buildings, internal gains and activity patterns usually have a stronger influence on loads. In such cases, the residential presets should be seen as a useful first-order approximation only;
- **Financial incentives:** Government support (subsidies, grants, tax incentives) can be reflected in the inputs, but are not considered dynamically;
- **Annual temporal resolution:** The calculations are based on annual energy totals rather than hourly or sub-hourly profiles. For example, time-of-use electricity tariffs are not yet explicitly implemented in the current blueprints;
- **Building-level focus:** The tool currently focuses on evaluations of individual installations rather than district-scale or networked GHP solutions;
- **Deterministic approach:** The current implementation does not quantify uncertainty through probabilistic methods. Sensitivity analysis provides a qualitative understanding of parameter impacts, but not statistical confidence intervals.

While limitations are present, they do not diminish the tool's utility for comparative assessment and pre-feasibility analysis. Rather, they define appropriate application contexts and exemplify where additional specialised analysis may be warranted.

7. Conclusion

The economic analysis blueprints developed in **Deliverable 4.1** provide a practical, standardised framework for evaluating GHP systems across different European contexts. By combining an LCC-based methodology with an associated Excel-based implementation, the blueprints enable users to conduct comparable techno-economic assessments that fairly represent the long-term value proposition of geothermal heating and cooling.

The illustrative results presented in this document highlight a central finding: when assessed over a 25-year period, GHP systems consistently achieve the lowest NPV and LCOE among the technologies compared. DH also emerges as a competitive option, while ASHPs, despite lower upfront costs, incur higher operating expenditure over time. Gas boilers represent the least economical alternative, with an NPV and LCOE nearly three times that of GHP systems.

These outcomes emphasise the importance of applying a life-cycle perspective when comparing heating and cooling technologies. The explicit treatment of GHP-specific economic characteristics, such as long asset lifetimes, residual value, and component replacement schedules, addresses a gap in conventional comparisons that often disadvantage high-upfront renewable technologies. The blueprints are already actively supporting portfolio evaluation in the project, generating insights to support GHP market development in Europe.