Supplementary material

A. Selection of alternatives

There are two options for the sewer system (gravity or LPS), three options for freeze protection (burial below the frost line, electric heat tracing or warm water heat tracing) and three options for residential heating (high temperature district heating, low temperature district heating, geothermal heat pumps), leading to eighteen possible combinations. However, combinations of warm water heat tracing with high temperature district heating or geothermal heat pumps (4 combinations) were discarded for technical reasons. This is because warm water heat tracing is made possible by using low temperature district heating [1]. Hence, the selection method was applied on the 14 possible combinations.

First, each combination was evaluated according to a set of three selection criteria (s_i) as described below.

S_1 data availability (scale: 0-3-6). Data are usually more available on conventional solutions (widely used) than on unconventional ones (rarely or never used). Combinations featuring conventional heating and conventional sewerage were attributed a score of six. Combinations with conventional heating or conventional sewerage were attributed a score of three. Finally, combinations with unconventional heating and unconventional sewerage were attributed a score of zero. High temperature district heating, geothermal heat pumps and deep buried gravity sewer were considered conventional while low temperature district heating, low pressure sewer and heat traced gravity sewer were considered unconventional.

S_2 innovation level (scale: 0-3-6). Starting from zero, 3 points were added for each innovative element featured by a combination. Warm water heat tracing, geothermal heat pumps and low temperature district heating were counted as innovative elements.

S_3 synergy level (scale: 0-2-4-6). The level of synergy between sanitation system and heating system was estimated for each combination. Starting from zero, 2 points were added for each sanitation-heating interaction featured by an alternative. The following interactions were considered: possibility of installation in the same trench, installation at the same depth, use of district heating for freeze protection of sanitation system.

The overall selection score was structured to give importance to combinations with good data availability, low or high innovation level and low or high synergy level. This was done to favour clear comparisons between traditional and innovative alternatives as well as separated and integrated approaches. The overall score was also structured to give equal importance to the three selection criteria. Equation S1 was used to compute the overall scores with $\overline{S_2}$ and $\overline{S_3}$ being mid-range values of S_2 and S_3 scores (3 for both). Criteria and overall scores are presented in Table S1 for each possible combination of sewer, freeze protection and heating system.

$$S = S_1 + 2\sqrt{S_2 - \overline{S_2}}^{\,2} + 2\sqrt{S_3 - \overline{S_3}}^{\,2} \qquad \text{(S1)}$$

The five combinations with highest overall score values were selected as alternatives for the multi-criteria analysis. These combinations are highlighted in bold in Table S1.

Table S1. Criteria and overall scores of fourteen possible combinations of sewer, freeze protection and heating system. HTDH: high temperature district heating, LTDH: low temperature district heating, GHP: geothermal heat pumps.

Combinations			Criteria scores			Overall selection score (S)
Heating	**Sewer**	**Freeze protection**	**Data availability**	**Innovation level**	**Synergy level**	
HDTH	**Gravity**	**Deep burial**	**6**	**0**	**2**	**14**
HDTH	Gravity	Electrical	3	0	4	11
HDTH	LPS	Deep burial	3	0	2	11
HDTH	LPS	Electrical	3	0	4	11
LTDH	Gravity	Deep burial	3	3	2	5
LTDH	Gravity	Electrical	0	3	4	2
LTDH	**Gravity**	**Warm water**	**0**	**6**	**6**	**12**
LTDH	LPS	Deep burial	0	3	2	2
LTDH	LPS	Electrical	3	3	4	5
LTDH	**LPS**	**Warm water**	**0**	**6**	**6**	**12**
GHP	**Gravity**	**Deep burial**	**6**	**0**	**0**	**18**
GHP	Gravity	Electrical	3	3	0	9
GHP	LPS	Deep burial	3	3	0	9
GHP	**LPS**	**Electrical**	**3**	**0**	**0**	**15**

B. Calculation of failure rates for the district heating options

Equation S2 was used to calculated the failure rates of the district heating system as experienced by the users (number of unmet heat demand events per household per year).

$$I_{7b} = \frac{\lambda_p * L * \bar{C}}{N} \qquad (S2)$$

In equation S2, L represents the networks length servicing the neighbourhood. In the case of Repisvaara South II, this corresponded to 3510 meters of newly built network and 2500 meters of the existing network. For alternatives A2 and A3, the length of newly built network was multiplied by 1,5 since 3 district heating pipes (feed, return and heat tracing) are installed instead of 2 for alternative A1 (feed and return). C represents the number of households serviced by a given pipe (e.g. 1 for a one family house connection, 211 for the main pipe feeding the whole neighbourhood). $\bar{C}$ is the average value of C over the network length L. A value of 112 serviced households was found for $\bar{C}$ for the district heating system of Repisvaara South II. λ_p is the district heating pipe failure rate. The λ_p value of 0,05 failure/km/year found by Åkerström [2] for pre-insulated pipes manufactured by "Powerpipe AB" was used in this study for the high temperature district heating option. For the low temperature district heating option, failure rates on EPS-PEX pipe solutions are not yet available. Therefore, a neutral assumption was made by assuming that failure rates on these pipes would be the same as on high temperature pipes (0,05 failure/km/year).

C. Radar diagrams

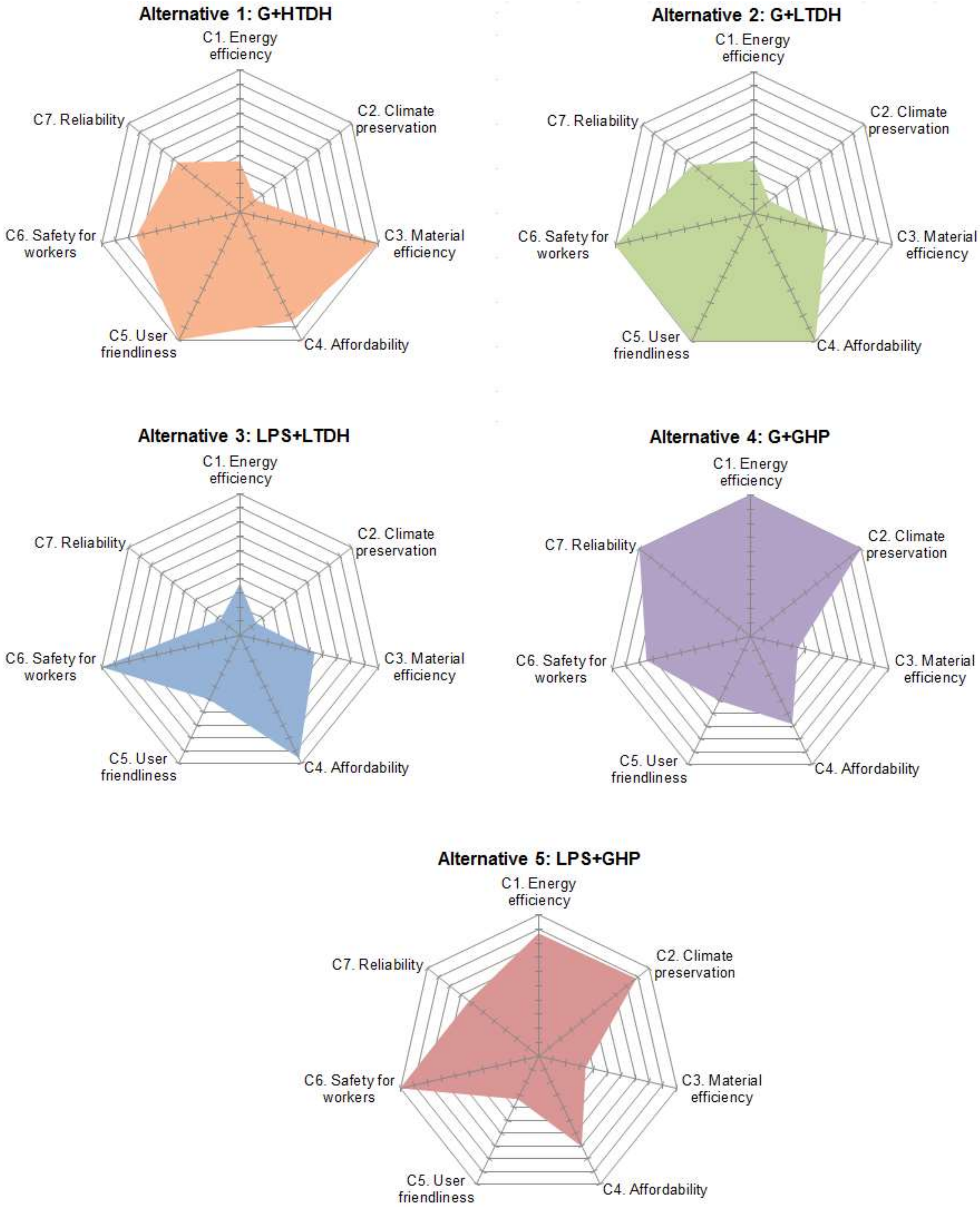

Figure S1. Criteria scores of the five studied alternatives. Scale from 0 (centre) to 100 (edge). Abbreviations: G: gravity sewer; LPS: Low pressure sewer; HTDH: high temperature district heating; LTDH: low temperature district heating; GHP: geothermal heat pump.

D. Determination of weights

Table S2. Determination of weights for the sustainability assessment based on the point distributions obtained during the budget allocation workshop.

Criteria	**Water sub-group**				**Planning sub-group**		**Energy sub-group**		**Housing sub-group**			**Mean of sub-group means**	**Standard deviation of sub-group means**	**Final weights**
	Person 1	Person 2	Person 3	**Mean**	Person 1	**Mean**	Person 1	**Mean**	Person 1	Person 2	**Mean**			
C1. Energy efficiency	21	16	21	**19**	21	**21**	24	**24**	33	33	**33**	**24**	5	**0.24**
C2. Climate preservation	5	11	5	**7**	5	**5**	4	**4**	3	3	**3**	**5**	2	**0.05**
C3. Material efficiency	5	11	5	**7**	5	**5**	10	**10**	3	3	**3**	**6**	3	**0.06**
C4. Affordability	21	26	21	**23**	32	**32**	21	**21**	22	22	**22**	**24**	4	**0.24**
C5. User friendliness	11	5	11	**9**	3	**3**	6	**6**	6	6	**6**	**6**	2	**0.06**
C6. Workers' safety	5	5	5	**5**	2	**2**	4	**4**	11	11	**11**	**6**	3	**0.06**
C7. Reliability	32	26	32	**30**	32	**32**	32	**32**	22	22	**22**	**29**	4	**0.29**

The energy stakeholder did not provide a point distribution during the workshop but preferred to rank the different criteria. The ranking was converted to a point repartition by using the average number of points given by the other sub-groups for each rank.

E. Sensitivity analysis

Table S3. Stability of the top-ranked alternative (A4: gravity sewer and geothermal heat pump) with regard to changes in input parameters. Abbreviations: f.u: functional unit, DH: district heating, r.u: residential unit, co: connection, NP: not possible, GHP: geothermal heat pump, COP: coefficient of performance LTDH: low temperature district heating.

Parameter	**Unit**	**Original value**	**Operation to change top alternative**	**New rank (new score)**				
				A1	A2	A3	A4	A5
Urban density	f.u / km of pipe	60.1	NP			NP		
Heat demand	kWh/year/r.u	11030	NP			NP		
Failure rate district heating	Failure/year/km	0.05	÷ 20	1 (76)	3 (75)	5 (60)	2 (76)	4 (63)
Failure rate geothermal heat pump	Failure/year/r.u	0.02	× 20	1 (76)	3 (75)	5 (60)	2 (76)	4 (64)
Blockage rate gravity sewer	Block./co./year	0.03	× 4.7	4 (62)	3 (64)	5 (61)	2 (86)	1 (86)
COP geothermal heat pump	-	4	÷ 2.8	3 (79)	1 (81)	5 (67)	2 (81)	4 (70)
Coal fraction in electricity mix	%	1.2	NP			NP		
Biomass fraction in DH mix	%	46	NP			NP		
Geothermal fraction in LTDH mix	%	0	+ 94	3 (77)	1 (89)	5 (75)	2 (89)	4 (77)
Linear cost gravity	€/meter	470	× 28	5 (50)	3 (65)	4 (51)	2 (75)	1 (75)
Lifespan GHP	years	20	÷ 11.1	3 (67)	1 (70)	5 (55)	2 (69)	4 (57)
Marginal DH cost	€/kWh	0.023	NP			NP		
Electricity price	€/kWh	0.08	NP			NP		

References

1. Pericault, Y.; Risberg, M.; Vesterlund, M.; Viklander, M.; Hedström, A. A novel freeze protection strategy for shallow buried sewer pipes: Temperature modelling and field investigation. *Water Sci. Technol.* **2017**, *76*, 294–301, doi:10.2166/wst.2017.174.
2. Åkerström, Å. Re-investment model for existing district heating networks (Reinvesteringsmodell för befintligt fjärrvärmenät, in Swedish). Thesis project, Technical Faculty of Lund University (LTH), **2014**.