***Supplementary material***

Techno-Economic Mapping for the Improvement of Shallow Geothermal Management in Southern Switzerland

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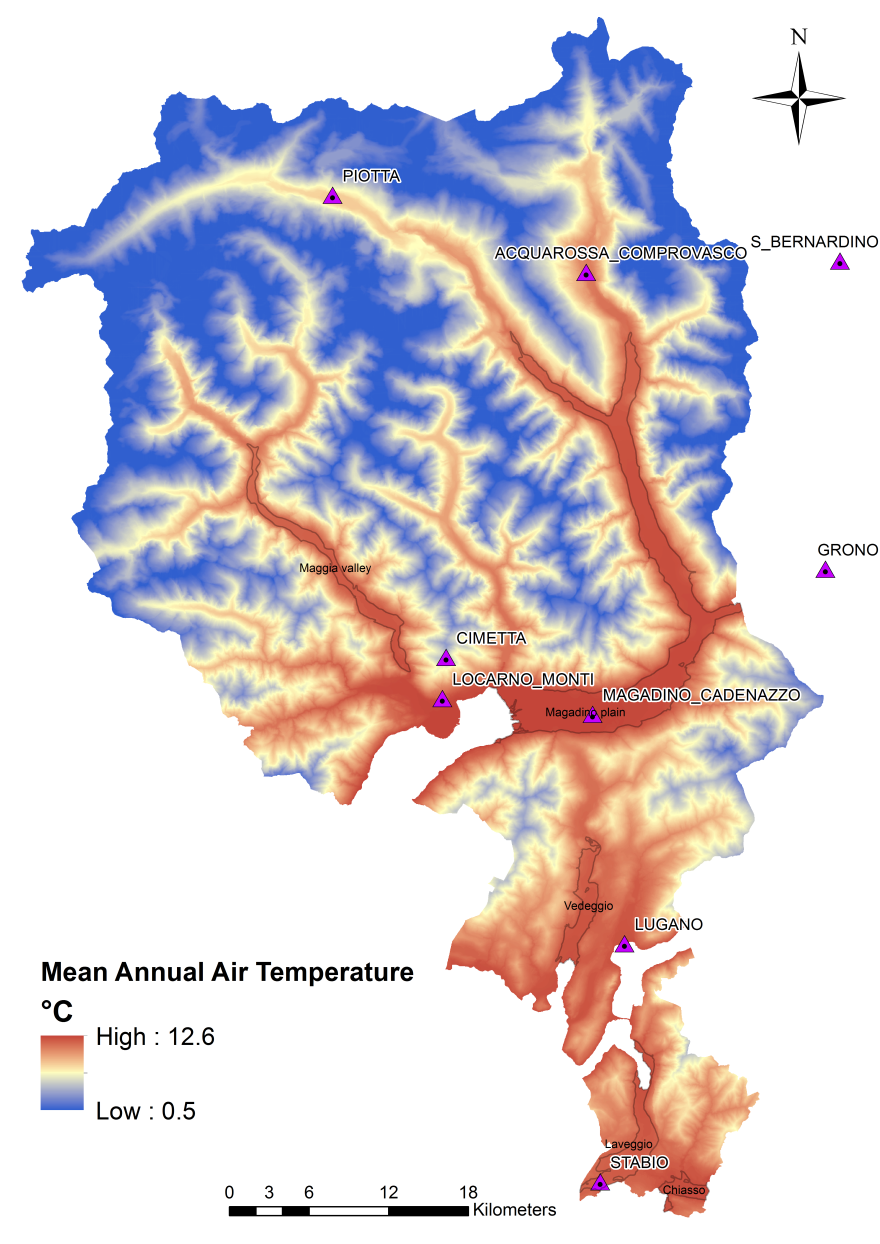


Figure S1 – MAAT map of Cantone Ticino with chosen air temperature MeteoSwiss stations

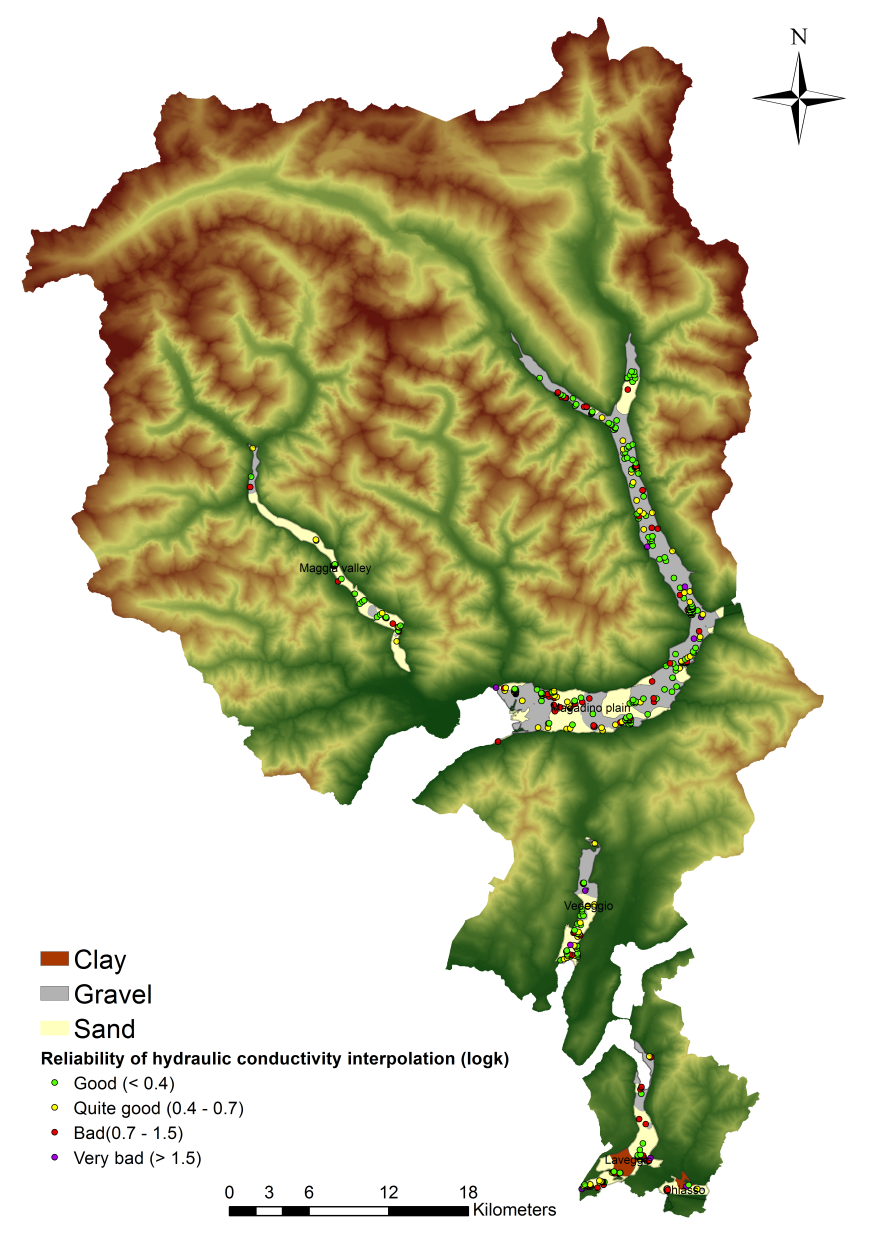


Figure S2 – Reliability of litho-textural characterization of the subsurface

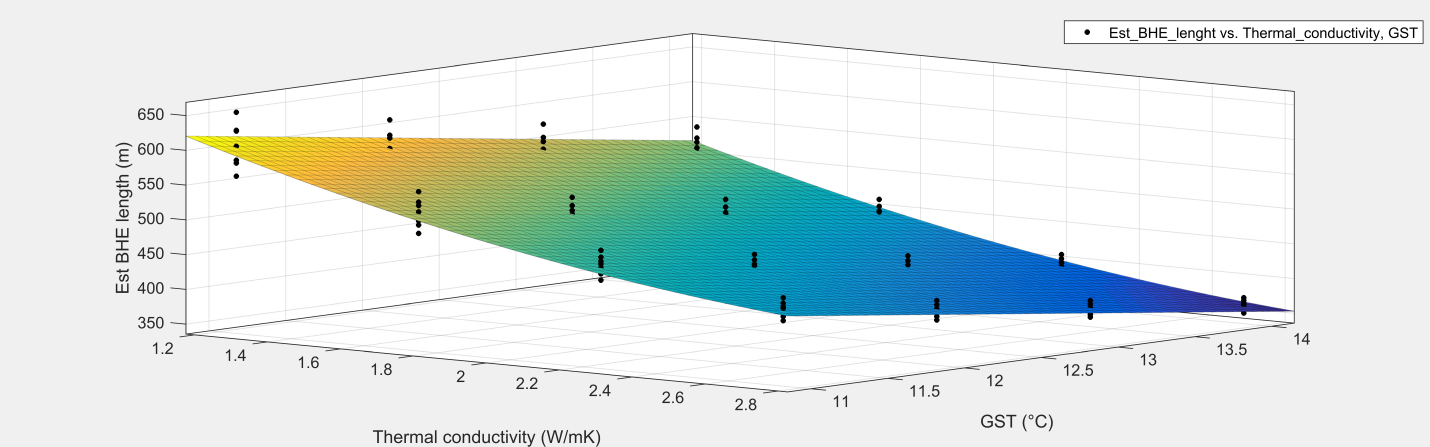


Figure S3 – 3D regression between thermal conductivity (x1), Ground Surface Temperature (x2) and estimated BHE length (y)

Table S1 – Measured thermal conductivity from TRT executed within Cantone Ticino. The first five TRTs are executed in predominant rock, while the Mendrisio one is executed within predominant unconsolidated deposits

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Site location | East | North | Altitude [m a.s.l.] | Measured λ [W/mK[ | Mapped λ [W/mK ] | Absolute difference [W/mK] |
| Barbengo | 714825 | 90863.5 | 282.7 | 3.06 | 2 | 1.06 |
| Olivone | 710926 | 152893 | 1433 | 3.82 | 3 | 0.82 |
| Lugano-Besso | 716140 | 96434 | 378.3 | 3.35 | 2 | 1.35 |
| Collina d'oro | 713935 | 91237.5 | 525.8 | 2.3 | 2.7 | 0.4 |
| Massagno | 716462 | 96674 | 366.8 | 3.26 | 2 | 1.26 |
| Mendrisio | 719892 | 80358 | 356 | 2.4 | 1.7 | 0.7 |

MAE: 0.93 W/mK; RMSE: 0.99 W/mK

Table S2 - 3D regression coefficients and fit for the identification of the BHE length regression

|  |  |
| --- | --- |
| Model type | 2nd grade polynomial:  f(x,y) = A + B\*x + C\*y + D\*x2 + E\*x\*y |
| Coefficients (with 95% confidence bounds): | A = 1236 (1113, 1359)  B = -269.1 (-340.2, -198)  C = -34.83 (-44.03, -25.62)  D = 34 (22.92, 45.08)  E = 2.47 (-1.963, 6.903) |
| Goodness of fit: | SSE: 30840  R2 : 0.9487  Adjusted R2: 0.947  RMSE: 15.8 m |

Table S3 - Summary of all the 128 EED simulations performed to identify the polynomial regression between λ, GST, BHE length

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Inputs | | | | | | | | |  | Outputs | | | Elaboration |
| Case n° | Ground surface temperature (°C) | Heat flux (mW/m2) | Thermal conductivity (W/mK) | Volumetric heat capacity (MJ/m3K) | Thermal diffusivity | Heat demand (kwh/year) | COP | Peak power (kW) | | Ltot (m) | Mean min t fluid (°C) | Mean max t fluid (°C) | Estimated peak heat extraction rate (W/m) |
| 1 | 11 | 25 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | | 654 | 4.6 | 9.1 | 28.7 |
| 2 | 11 | 25 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | | 628 | 4.4 | 9.0 | 29.9 |
| 3 | 11 | 25 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | | 565 | 4.9 | 9.1 | 33.2 |
| 4 | 11 | 25 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | | 545 | 4.8 | 9.0 | 34.4 |
| 5 | 11 | 25 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | | 506 | 5.2 | 9.3 | 37.1 |
| 6 | 11 | 25 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | | 490 | 5.1 | 9.2 | 38.2 |
| 7 | 11 | 25 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | | 463 | 5.4 | 9.4 | 40.5 |

**Table S3.** Cont.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 8 | 11 | 25 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 450 | 5.3 | 9.4 | 41.7 |
| 9 | 11 | 35 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 627 | 4.8 | 9.5 | 29.9 |
| 10 | 11 | 35 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 602 | 4.7 | 9.4 | 31.1 |
| 11 | 11 | 35 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 550 | 5.1 | 9.4 | 34.1 |
| 12 | 11 | 35 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 530 | 5.0 | 9.3 | 35.4 |
| 13 | 11 | 35 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 496 | 5.3 | 9.5 | 37.8 |
| 14 | 11 | 35 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 481 | 5.2 | 9.4 | 39.0 |
| 15 | 11 | 35 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 455 | 5.5 | 9.6 | 41.2 |
| 16 | 11 | 35 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 443 | 5.4 | 9.5 | 42.3 |
| 17 | 11 | 45 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 605 | 5.1 | 10.0 | 31.0 |
| 18 | 11 | 45 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 581 | 4.9 | 9.8 | 32.3 |
| 19 | 11 | 45 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 536 | 5.2 | 9.7 | 35.0 |
| 20 | 11 | 45 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 517 | 5.1 | 9.6 | 36.3 |
| 21 | 11 | 45 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 486 | 5.4 | 9.7 | 38.6 |
| 22 | 11 | 45 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 472 | 5.3 | 9.6 | 39.8 |
| 23 | 11 | 45 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 448 | 5.6 | 9.8 | 41.8 |
| 24 | 11 | 45 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 436 | 5.5 | 9.7 | 43.0 |
| 25 | 11 | 55 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 585 | 5.3 | 10.4 | 32.0 |
| 26 | 11 | 55 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 562 | 5.1 | 10.2 | 33.3 |
| 27 | 11 | 55 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 523 | 5.4 | 10.0 | 35.8 |
| 28 | 11 | 55 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 505 | 5.3 | 9.9 | 37.1 |
| 29 | 11 | 55 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 477 | 5.6 | 9.9 | 39.3 |
| 30 | 11 | 55 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 463 | 5.5 | 9.8 | 40.5 |
| 31 | 11 | 55 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 442 | 5.7 | 9.9 | 42.4 |
| 32 | 11 | 55 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 430 | 5.6 | 9.9 | 43.6 |
| 101 | 12 | 25 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 613 | 5.0 | 9.8 | 30.6 |
| 102 | 12 | 25 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 587 | 4.8 | 9.7 | 31.9 |
| 103 | 12 | 25 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 527 | 5.3 | 9.9 | 35.6 |
| 104 | 12 | 25 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 508 | 5.3 | 9.8 | 36.9 |
| 105 | 12 | 25 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 470 | 5.7 | 10.1 | 39.9 |
| 106 | 12 | 25 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 456 | 5.6 | 10.0 | 41.1 |
| 107 | 12 | 25 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 429 | 5.9 | 10.3 | 43.7 |
| 108 | 12 | 25 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 417 | 5.9 | 10.2 | 45.0 |
| 109 | 12 | 35 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 591 | 5.2 | 10.2 | 31.7 |
| 110 | 12 | 35 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 567 | 5.1 | 10.1 | 33.1 |
| 111 | 12 | 35 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 515 | 5.5 | 10.2 | 36.4 |
| 112 | 12 | 35 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 496 | 5.4 | 10.1 | 37.8 |
| 113 | 12 | 35 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 462 | 5.8 | 10.3 | 40.6 |
| 114 | 12 | 35 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 448 | 5.7 | 10.2 | 41.9 |
| 115 | 12 | 35 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 423 | 6.1 | 10.4 | 44.4 |
| 116 | 12 | 35 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 411 | 6.0 | 10.4 | 45.6 |

**Table S3.** Cont.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 117 | 12 | 45 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 572 | 5.4 | 10.6 | 32.8 |
| 118 | 12 | 45 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 549 | 5.3 | 10.5 | 34.2 |
| 119 | 12 | 45 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 503 | 5.7 | 10.5 | 37.3 |
| 120 | 12 | 45 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 485 | 5.6 | 10.4 | 38.7 |
| 121 | 12 | 45 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 454 | 5.9 | 10.5 | 41.3 |
| 122 | 12 | 45 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 440 | 5.8 | 10.4 | 42.6 |
| 123 | 12 | 45 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 417 | 6.2 | 10.6 | 45.0 |
| 124 | 12 | 45 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 406 | 6.1 | 10.5 | 46.2 |
| 125 | 12 | 55 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 554 | 5.7 | 11.0 | 33.8 |
| 126 | 12 | 55 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 533 | 5.5 | 10.9 | 35.2 |
| 127 | 12 | 55 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 492 | 5.8 | 10.8 | 38.1 |
| 128 | 12 | 55 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 475 | 5.7 | 10.6 | 39.5 |
| 129 | 12 | 55 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 446 | 6.0 | 10.7 | 42.0 |
| 130 | 12 | 55 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 433 | 5.9 | 10.6 | 43.3 |
| 131 | 12 | 55 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 412 | 6.3 | 10.8 | 45.5 |
| 132 | 12 | 55 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 401 | 6.2 | 10.7 | 46.8 |
| 201 | 13 | 25 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 577 | 5.4 | 10.5 | 32.5 |
| 202 | 13 | 25 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 552 | 5.2 | 10.4 | 34.0 |
| 203 | 13 | 25 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 494 | 5.8 | 10.7 | 38.0 |
| 204 | 13 | 25 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 475 | 5.7 | 10.6 | 39.5 |
| 205 | 13 | 25 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 438 | 6.2 | 10.9 | 42.8 |
| 206 | 13 | 25 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 425 | 6.1 | 10.9 | 44.1 |
| 207 | 13 | 25 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 399 | 6.5 | 11.1 | 47.0 |
| 208 | 13 | 25 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 388 | 6.4 | 11.1 | 48.3 |
| 209 | 13 | 35 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 558 | 5.6 | 10.9 | 33.6 |
| 210 | 13 | 35 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 535 | 5.4 | 10.8 | 35.0 |
| 211 | 13 | 35 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 483 | 6.0 | 11.0 | 38.8 |
| 212 | 13 | 35 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 465 | 5.9 | 10.9 | 40.3 |
| 213 | 13 | 35 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 431 | 6.3 | 11.1 | 43.5 |
| 214 | 13 | 35 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 418 | 6.2 | 11.1 | 44.8 |
| 215 | 13 | 35 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 394 | 6.6 | 10.3 | 47.6 |
| 216 | 13 | 35 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 383 | 6.5 | 11.2 | 48.9 |
| 217 | 13 | 45 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 541 | 5.8 | 11.3 | 34.7 |
| 218 | 13 | 45 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 520 | 5.7 | 11.2 | 36.1 |
| 219 | 13 | 45 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 473 | 6.1 | 11.3 | 39.6 |
| 220 | 13 | 45 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 456 | 6.0 | 11.2 | 41.1 |
| 221 | 13 | 45 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 425 | 6.4 | 11.3 | 44.2 |
| 222 | 13 | 45 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 412 | 6.3 | 11.2 | 45.5 |
| 223 | 13 | 45 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 389 | 6.7 | 11.4 | 48.2 |
| 224 | 13 | 45 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 379 | 6.6 | 11.4 | 49.5 |
| 225 | 13 | 55 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 526 | 6.1 | 11.7 | 35.7 |

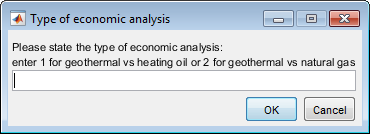
**Table S3.** Cont.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 226 | 13 | 55 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 506 | 5.8 | 11.6 | 37.1 |
| 227 | 13 | 55 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 464 | 6.3 | 11.5 | 40.4 |
| 228 | 13 | 55 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 448 | 6.2 | 11.4 | 41.9 |
| 229 | 13 | 55 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 418 | 6.6 | 11.5 | 44.8 |
| 230 | 13 | 55 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 406 | 6.4 | 11.4 | 46.2 |
| 231 | 13 | 55 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 385 | 6.8 | 11.6 | 48.7 |
| 232 | 13 | 55 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 375 | 6.7 | 11.5 | 50.1 |
| 301 | 14 | 25 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 543 | 5.8 | 11.2 | 34.5 |
| 302 | 14 | 25 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 521 | 5.6 | 11.2 | 36.0 |
| 303 | 14 | 25 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 464 | 6.3 | 11.5 | 40.4 |
| 304 | 14 | 25 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 447 | 6.2 | 11.4 | 42.0 |
| 305 | 14 | 25 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 410 | 6.7 | 11.8 | 45.7 |
| 306 | 14 | 25 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 398 | 6.6 | 11.7 | 47.2 |
| 307 | 14 | 25 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 373 | 7.1 | 12.0 | 50.3 |
| 308 | 14 | 25 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 363 | 7.0 | 11.9 | 51.7 |
| 309 | 14 | 35 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 527 | 6.0 | 11.6 | 35.6 |
| 310 | 14 | 35 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 506 | 5.8 | 11.5 | 37.1 |
| 311 | 14 | 35 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 454 | 6.4 | 11.8 | 41.3 |
| 312 | 14 | 35 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 438 | 6.3 | 11.7 | 42.8 |
| 313 | 14 | 35 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 404 | 6.8 | 12.0 | 46.4 |
| 314 | 14 | 35 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 392 | 6.7 | 11.9 | 47.8 |
| 315 | 14 | 35 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 369 | 7.2 | 12.1 | 50.9 |
| 316 | 14 | 35 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 359 | 7.1 | 12.1 | 52.3 |
| 317 | 14 | 45 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 513 | 6.2 | 12.0 | 36.6 |
| 318 | 14 | 45 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 492 | 6.0 | 11.9 | 38.1 |
| 319 | 14 | 45 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 446 | 6.6 | 12.0 | 42.1 |
| 320 | 14 | 45 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 431 | 6.5 | 11.9 | 43.5 |
| 321 | 14 | 45 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 399 | 6.9 | 12.1 | 47.1 |
| 322 | 14 | 45 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 387 | 6.8 | 12.1 | 48.5 |
| 323 | 14 | 45 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 365 | 7.2 | 12.3 | 51.4 |
| 324 | 14 | 45 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 355 | 7.2 | 12.2 | 52.8 |
| 325 | 14 | 55 | 1.25 | 1.5 | 0.0000008 | 30000 | 4 | 25 | 499 | 6.4 | 12.4 | 37.5 |
| 326 | 14 | 55 | 1.25 | 2 | 0.0000006 | 30000 | 4 | 25 | 480 | 6.2 | 12.2 | 39.1 |
| 327 | 14 | 55 | 1.75 | 1.5 | 0.0000012 | 30000 | 4 | 25 | 438 | 6.7 | 12.3 | 42.8 |
| 328 | 14 | 55 | 1.75 | 2 | 0.0000009 | 30000 | 4 | 25 | 423 | 6.6 | 12.2 | 44.3 |
| 329 | 14 | 55 | 2.25 | 1.5 | 0.0000015 | 30000 | 4 | 25 | 393 | 7.1 | 12.3 | 47.7 |
| 330 | 14 | 55 | 2.25 | 2 | 0.0000011 | 30000 | 4 | 25 | 382 | 6.9 | 12.2 | 49.1 |
| 331 | 14 | 55 | 2.75 | 1.5 | 0.0000018 | 30000 | 4 | 25 | 361 | 7.3 | 12.4 | 51.9 |
| 332 | 14 | 55 | 2.75 | 2 | 0.0000014 | 30000 | 4 | 25 | 351 | 7.3 | 12.3 | 53.4 |

**Economic tool (developed in MATLAB 2016a version)**

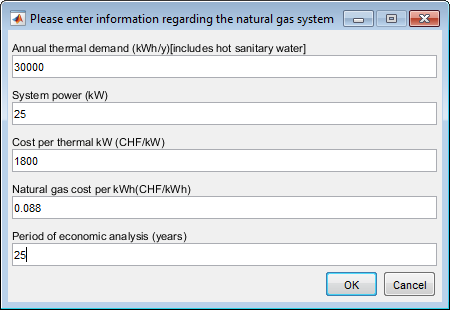
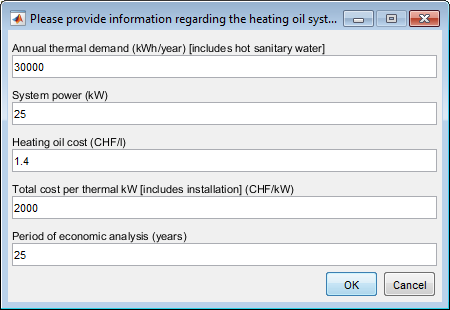
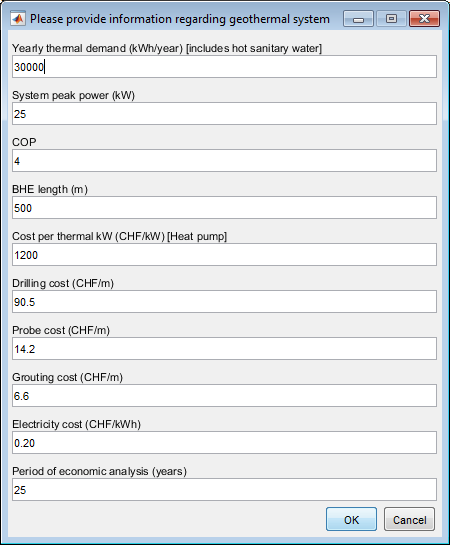
The tool uses an interface developed in Matlab, which drives the user to enter the requested values for the economic analysis through a series of dialog boxes. The scheme of the MATLAB/OCTAVE economic tool is the following:

* It initially asks the user to choose which economic analysis will be performed, geothermal against heating oil/fuel or geothermal against methane;

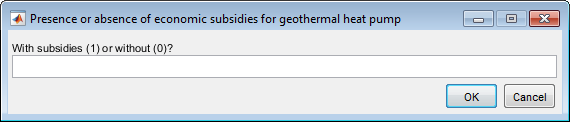


* It asks the user to provide it with a series of information to estimate the initial investment costs for geothermal system, which for simplicity is estimated from the cost of the heat pump plus the costs per meter of perforation (composed of drilling costs, probe costs and grouting costs). The prices are expressed in Swiss Francs, but upon request it could be delivered considering €. At the time of writing 1€ = 1.15 CHF;
* The user must also enter the duration of the economic analysis in years;

All the default values used for the economic analysis presented in the manuscript are reported in the following figures, except for required BHE length, which was varied to find a relation between BHE length and payback period:

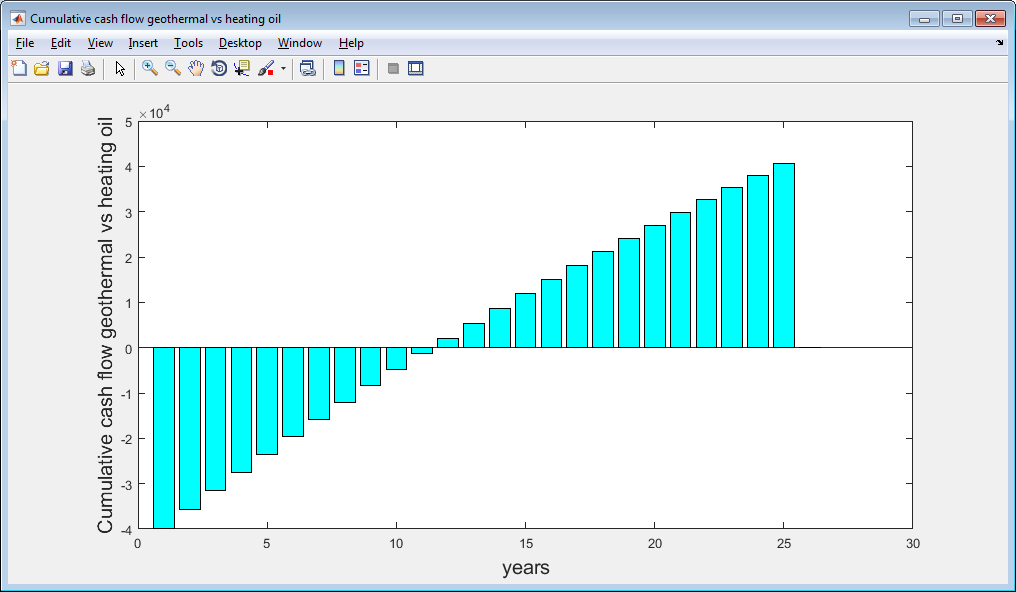


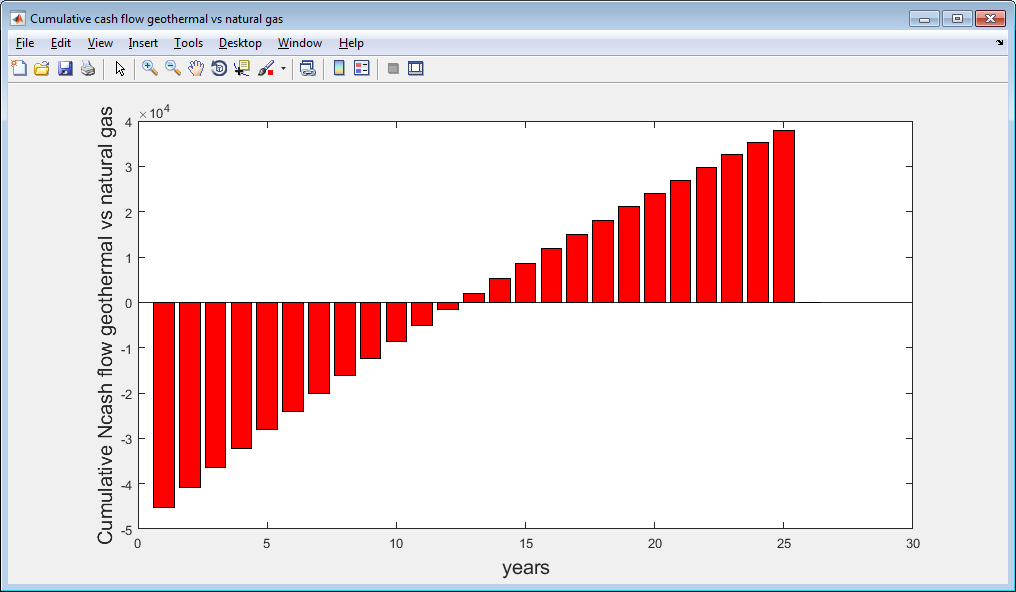
* After having calculated the initial investment, the tool estimates the maintenance costs per year for geothermal systems (set to 1% of the investment per year) and the electricity cost;
* If the comparison with heating oil system was selected, then the tool asks the user to provide it with information on the fuel system and on the fuel cost. In this case the user must also enter all-inclusive cost per kW (it is a rough estimate, including installation, test and considering at least one replacement every 15 years);
* If the comparison with methane system was selected, then the tool asks the user to provide it with information on the methane and on the methane cost. In this case the user must also enter all-inclusive cost per kW of the furnace (it is a rough estimate, including installation, test and considering at least one replacement every 15 years);
* The tool then calculates the maintenance costs of the chosen system (3% per year of the investment for heating oil and 8% per year for methane, which include cleaning of exhaust stack, control of combustion and cleaning of the tank);
* The tool then calculates the yearly costs for geothermal, oil fuel and methane, including CO2 tax (introduced in Switzerland to discourage from the use of fossil fuels) and the loss of efficiency for oil fuel and methane systems during time (from an efficiency of 0.86 to 0.72 for oil fuel furnace and from 0.92 to 0.68 for methane furnace during the number of years set for the economic analysis);
* It asks if the user wants to implement in the estimation of the initial investment the Cantonal subsidy for the heat pump in replacement of the heating oil system (\*see the footnote at the end of this section)



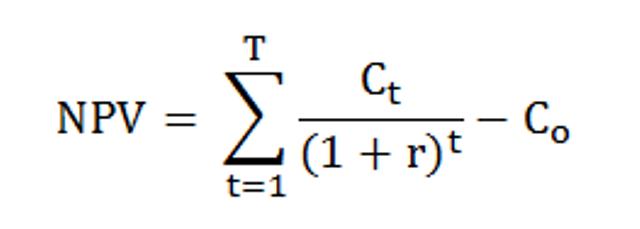
The subsidies for the geothermal heat pump in Canton Ticino are valid **ONLY IF** there is the replacement of **the heating oil system** with a geothermal one, they do not apply for natural gas systems. The subsidies are the following:

* + Up to or equal to 15 kWth of thermal capacity: CHF 5000 + CHF 180/ kWth;
  + More than 15 kWth of thermal capacity: CHF 4000 + CHF 180/ kWth;
* It then estimates the potential savings per year produced by the geothermal system and plots a graphic with the years as x and the cumulative cash flow as y. The cumulative cash flow is simply the net cash flow (costs for geothermal system minus the costs for a heating oil/natural gas one) expressed in Swiss Francs (CHF), calculated for every year or time-step of the economic analysis. Negative cash flow means that for the first years, the geothermal solution would cost more than a fossil fuel one, but during time this discrepancy tends to decrease until the difference between the two costs is equal to zero, which is the payback period. The payback period using cumulative cash flow can be estimated visually using the bar graph (where the cash flow goes to 0), while the tool also prints a rough payback period by averaging the estimated savings, but that is not as accurate as the cash flow (it is underestimated). The calculated payback period is where the cash flow goes to 0 and starts being positive (in the example, after 12 and 13 years respectively);





* The tool also calculates the NPV (Net Present Value) for the investment. The net present value, or NPV, is one of the most common methods used to evaluate investments. At its simplest, NPV is the present value computed by using the project cost of capital as the discount rate of cash inflows, minus the present value of cash outflows, including the initial investment. NPVis calculated with the following formula:



where

Ct = net cash inflow-outflows during a single period t

C0= initial investment

r = discount rate or return that could be earned in alternative investments

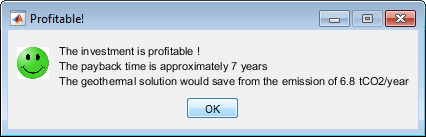
t = number of time period (e.g.. First year, second year…)

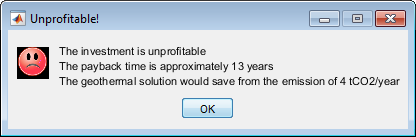
T=time of economic analysis (e.g. 25 years)

If the present value of the cash flows, discounted at the cost of capital, exceeds the cost of the investment, then the investment will add to the value of the company, in this case of the renewable energy project.

For more information on NPV please visit <https://www.investopedia.com/terms/n/npv.asp>.

* if NPV >0 then the investment is profitable, NPV = 0 does not add any monetary value; elsewhere if NPV is < 0 the investment is not profitable, therefore not suggested; the user should invest in some other projects;
* The tool finally calculates the estimated CO2 emissions for all type of technologies and the amount of CO2 emissions that could be yearly saved with the use of a geothermal system instead of a fossil fuel one or methane one.





\*<https://www3.ti.ch/CAN/RLeggi/public/raccolta-leggi/legge/numero/9.1.7.1.8>

Of course we implemented some referential values within the economic tool, some of them are changeable in the dialog boxes (the required inputs from the user) and some of them are not (with the exception of directly changing the code). This is a preliminary estimate with the data in our possession and the inputs contained in the tool are largely adjustable depending on the user knowledge.

The tool is contained in a stand-alone MATLAB executable or in GNU OCTAVE functions and scripts, which can be requested to [rodolfo.perego@supsi.ch](file:///C:\Users\mcphee\AppData\Local\Temp\Temp2_energies-416921-supplementary.zip\rodolfo.perego@supsi.ch). To run the executable MATLAB software or MATLAB libraries must be installed on the PC. For people not having a MATLAB license, the executable can also contain the installation of these libraries. For OCTAVE users, an executable is not available: however, you can use functions and scripts.