LCA guidelines for geothermal installations

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December 11st, 2020

GEOENVI Project
Tackling the environmental concerns for deploying geothermal energy in Europe

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No [818242 — GEOENVI]
A wide diversity of geothermal energy exploitation impacts

- **Acoustic effects** (noise pollution during drilling, construction and operations)
- **Thermal effects** (thermal pollution, release of vapor into the air, heating and cooling of the soil due to the extraction or reinjection of fluids)
- **Visual/surface effects** (land use, biodiversity disturbance)
- **Physical effects** (induced seismicity and landslides, micro-seismicity, soil subsidence, geological risk, depletion of groundwater resources, natural radioactivity)
- **Chemical effects** (emissions into the atmosphere, non-condensable gases, reinjection of fluids, discharge of liquid and solid substances)

Click the following link for more details on environmental risks and impacts related to geothermal installations:
https://geoenvi.brgm.fr/
Life Cycle Assessment (LCA) Methodology

LCA Approach

- ISO Standard
- Comprehensive approach
- Multicriteria assessment
- Life cycle thinking
- International strategy to compare energy pathways

RESOURCES

- Raw Material Extraction
- Processing & Production
- Use Phase

“From cradle to grave.”

Recycle & Reuse

Dismantling & Disposal

Health and Environment

- Climate Changes
- Eutrophication
- Acidification

Resources

- Energy
- Raw Materials
- Water

From cradle to grave.
LCA studies literature review: technology representativity

<table>
<thead>
<tr>
<th>Type of geothermal systems</th>
<th>GHG in gCO₂eq/kWh Mediane estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced Geothermal Systems (EGS) Binary</td>
<td>32</td>
</tr>
<tr>
<td>Hydrothermal (HT) Flash</td>
<td>47</td>
</tr>
<tr>
<td>Hydrothermal (HT) Binary</td>
<td>11</td>
</tr>
</tbody>
</table>

26 LCA studies eligible among 180 studies (Harmonized method, Heath and Man, NREL, 2012)
26 LCA studies *eligible* among 180 studies
(Harmonized method, Heath and Man, NREL, 2012)
Life Cycle Assessment

**Goal definition**
- Intended application
- Methods, assumptions, limitations
- Reason and decision context

**Scope definition**
- Functional unit and reference flow
- Life cycle inventory modeling - MULTIFUNCTIONALITY
- System boundaries and cut-off criteria
- Approaches: cradle to grave, cradle to gate, gate to gate, ....

**Life cycle inventory**
Data collection on elementary flows which are crossing the system boundaries and interacting with the environment (resources taken from nature and emissions to air, water and soil)

**Life cycle Impact Analysis**
Translation of the LCI elementary flows into impact categories
→ for geothermal it is important to choose LCIA appropriately as the emissions are not conventional: \(H_2S, Hg\) etc... what type of impact: local or global; where in the cause-effect chain? Midpoint vs endpoint
**LCA Guidelines for geothermal installations**

- **Motivation**
  - To offer guidance for consistency, balance, and quality of Life Cycle Assessment (LCA).
  - To enhance the credibility of the findings from LCAs on geothermal systems.
  - To cover the most sensitive aspects of each step of a LCA applied to geothermal systems.

- **Beneficiary**
  - LCA practitioner and geothermal experts.
  - Challenge to produce in a concise manner guidelines ready to use for any type of geothermal installations fulfilling LCA ISO standards (14040 and 14044).

- **Objective**
  - To provide guidance on how to establish the life cycle inventories (LCI) of geothermal systems.
  - To provide guidance on selection of life cycle impact assessment (LCIA) and impact category indicators regarding the LCA of geothermal energy (electricity, heat or combined systems).

- **Scope**
  - LCA results applying these guidelines could contribute to a sustainability assessment of geothermal projects and does not claim to be exhaustive and exclusive in examining all potential environmental issues.
  - LCA could be accompanied by other environmental assessment criteria, which can consider site-dependent matters or whose evaluation involves social or qualitative acceptance.

(*) Conceptualized and developed by: ARMINES and CSGI with contributions from Electricité Strasbourg and VITO in the framework of the GEOENVI Project.
LCA Guidelines for geothermal installations

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• Methodological Guidelines
• Specific aspects of geothermal energy production
• Goal and scope definition
• Life Cycle Inventory (LCI)
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• Reporting and communication
• References

3 Technical Appendixes:

• Short guide to the use of Exergy as an allocation scheme in geothermal installations
• Reference average values as a support for modelling the inventory (based on GEOENVI case studies)
• Primary Energy Saving (PES)
• Additional Appendix in the foreseen second version: “Renewable Energies: Geothermal Heat and Power versus PV and Wind – A case study using exergy and PES”
Goal and scope definition

Functional unit

1) Power production only
   • kWh of electricity delivered to the grid or a user (kWhel)

2) Heating/cooling production only
   • kWh of heat delivered to the grid or a user (kWhth)

3) Multifunctional approach

System boundaries

Lifetime: 30 years (activity of the plant)
Multi-functionality: selection of an appropriate allocation procedure

LCA often deals with multi-purpose processes, having multiple products. In the case of geothermal plants, there is a wide variability among the installations and their power production. Two different allocation schemes can be applied to the wide diversity of geothermal installations:

➢ Share between the co-products > 75%
  system expansion with a substitution model for the co-products

➢ Share between the co-products < 75%
  Exergy content (Appendix 1).
## Selection of case studies for the LCA guidelines application in GEOENVI

<table>
<thead>
<tr>
<th>Geothermal source type</th>
<th>Bagnore (Italy)</th>
<th>Rittershoffen (France)</th>
<th>Hellisheidi (Iceland)</th>
<th>Balmatt (Belgium)</th>
<th>Demo Plant (Hungary)</th>
<th>Dora-II (Turkey)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid - hydrothermal</td>
<td>Liquid- EGS</td>
<td>Liquid/Vapour-hydrothermal</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>Energy generation technology</td>
<td>Flash</td>
<td>Direct heat use</td>
<td>Single and double flash</td>
<td>Direct use + ORC</td>
<td>ORC</td>
<td>ORC</td>
</tr>
<tr>
<td>Final energy use</td>
<td>Electricity + Heat</td>
<td>Industrial heat use</td>
<td>Electricity + Heat</td>
<td>Heat + Electricity (self-consumption)</td>
<td>Electricity</td>
<td>Electricity</td>
</tr>
<tr>
<td>Installed capacity</td>
<td>61 MWe 21.1 MWth</td>
<td>27 MWth</td>
<td>303.3 MWe 133 MWth</td>
<td>8 MWth 0.25 MWe</td>
<td>3.75 MWe</td>
<td>9.5 MWe</td>
</tr>
</tbody>
</table>
Life Cycle Inventory

- Materials and energy requirements to build subsurface, surface infrastructures and equipment/components & drilling of the wells.
- Recommendations on the reporting of the type of direct emissions and receiving environmental compartment (e.g. atmospheric emissions, effluents, etc.) are provided for each of these sub-systems.
- Use of primary data is priority, otherwise reference/average values as given in Appendix 2

### Materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>Unit</th>
<th>Reference value MIN-MAX (Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel, unalloyed</td>
<td>kg/well</td>
<td>7 428 (RT) – 17 660 (DO) (13 221)</td>
</tr>
<tr>
<td>Steel, stainless INOX 316 L</td>
<td>kg/well</td>
<td>16 (HL)</td>
</tr>
<tr>
<td>Concrete</td>
<td>kg/well</td>
<td>18 (HL) – 18 520 (BG) (9 269)</td>
</tr>
<tr>
<td>Portland cement</td>
<td>kg/well</td>
<td>13 771 (RT) – 259 286 (BG) (117 686)</td>
</tr>
<tr>
<td>Aluminium</td>
<td>kg/well</td>
<td>1 218 (HL) – 1 500 (DO) (1 359)</td>
</tr>
<tr>
<td>Iron</td>
<td>kg/well</td>
<td>4 000 (DO) – 8 568 (BG) (6284)</td>
</tr>
<tr>
<td>Excavation</td>
<td>m³/well</td>
<td>250 (DO) – 6 851 (RT) (1 940)</td>
</tr>
<tr>
<td>Filling</td>
<td>m³/well</td>
<td>250 (DO) – 3 135 (RT) (1 723)</td>
</tr>
</tbody>
</table>

Default values available in Appendix 2: Example for wellhead construction

- **RT**: Rittershoffen
- **HL**: Hellisheidi
- **DO**: DORA II
- **BG**: Bagnore
# Life Cycle Impact Assessment method based on the EF V3.0 (example for 3 impact indicators)

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Unit</th>
<th>Indicator/Method</th>
<th>Version LCIA method</th>
<th>Source LCIA method</th>
<th>Level of priority</th>
<th>Level of robustness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change</td>
<td>kg CO₂ eq</td>
<td>Radiative forcing as Global Warming Potential (GWP100)</td>
<td>1.0.5 (land use, land use change, biogenic), 1.0.8 (fossil), 4.0.16</td>
<td>IPCC 2013</td>
<td>High</td>
<td>I</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>kg CFC-11 eq</td>
<td>Steady-state ozone depletion potential</td>
<td>2.0.12</td>
<td>WMO 1999</td>
<td>Low</td>
<td>I</td>
</tr>
<tr>
<td>Human toxicity cancer effects</td>
<td>CTUh</td>
<td>Comparative toxic unit for humans as provided in the USEtox 2.1. Factors have been applied on inorganics and metals to account for the fact that USEtox has been designed for organic substances.</td>
<td>1.0.3</td>
<td>Rosenbaum et al., 2008</td>
<td>High</td>
<td>III</td>
</tr>
</tbody>
</table>

LEVEL OF PRIORITY (specific to Geothermal installations) & LEVEL OF ROBUSTNESS (scientifical ground)
### List of impact categories identified as high priority for geothermal installations

<table>
<thead>
<tr>
<th>Impact Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>climate change total</td>
</tr>
<tr>
<td>freshwater ecotoxicity</td>
</tr>
<tr>
<td>freshwater and terrestrial acidification</td>
</tr>
<tr>
<td>mineral and metal resource depletion</td>
</tr>
<tr>
<td>fossil resource depletion</td>
</tr>
<tr>
<td>human non-carcinogenic effects</td>
</tr>
<tr>
<td>human carcinogenic effects</td>
</tr>
</tbody>
</table>
Additional covered aspects in the Guidelines

Reporting Inorganic emission with toxicity impacts in addition to the recommended impact categories

- As, B, Ar, Hg, Rn, Sb, $H_2S$

Additional metrics
PES (Primary Energy Saving) & Energy Pay-Back Time

Reporting & Communication section

- Methodological setting
- Parameter choices
- LCI details and assumptions
- Indication on what should be reported in figure and table captions
- .....
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https://www.geoenvi.eu/lca-for-geothermal/
