Training materials for GEOENVI's Life Cycle Assessment of deep geothermal installations

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Authors

In alphabetical order: Isabelle Blanc (MINES ParisTech); Mélanie Douziech (MINES ParisTech); Nicola Ferrara (Italian Centre for Colloid and Surface Science); Virginie HARCOUËT-MENOU (VITO); Maria Laura Parisi (Università di Siena); Paula Pérez-López (MINES ParisTech) Guillaume Ravier (ES Géothermie); Lorenzo Tosti (Italian Centre for Colloid and Surface Science).

Editors

Dario Bonciani (COSVIG); Valeria Mazzagatti (EGEC Geothermal).

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Introduction

LCA (Life Cycle Assessment) is an established approach to quantify and account for potential environmental impacts of goods and services during their entire life cycle. Originally focused on accounting for current or past impacts in existing projects, LCA is increasingly used to compare future developments and ease the decision-making process.

However, the LCA framework proposed is general and not tailored to energy systems and deep geothermal energy so that LCA practitioners face a variety of choices. LCA results of similar energy systems can, as a result, vary greatly.

The GEOENVI research project proposes **guidelines to harmonize current LCA practices applied to geothermal plants** in different geological settings throughout their lifetime.

GEOENVI has also developed a **newly integrated methodological framework for non-LCA experts** to assess the potential environmental impacts of geothermal energy systems. Statistical analysis (Global Sensitivity Analysis / GSA) is used to generate simplified parameterized models starting from extensive, parameterised LCAs. These simplified models allow a multi-criteria analysis of geothermal installations based on a low number of parameters. Such approach has initially developed for wind turbines and Enhanced Geothermal Systems.

GEOENVI generated simplified models for four different types of deep geothermal plants: CHP (combined Heat and Power), EGS (enhanced geothermal systems), flash power plant with limited heat production, heat production with small ORC.

Once generated, simplified models can be easily used by non-LCA experts. However, their generation through the protocol proposed by the GEOENVI project, requires expert knowledge in LCA and a good understanding of the analysed geothermal installation type. In addition, the implementation of the protocol requires abilities to use the Python programming language.

In the following pages, the reader will find support materials for the training sessions on LCA and simplified models for deep geothermal energy projects. In the last page the reader will find the reference to more specific online resources.

Visit the project website www.geoenvi.eu to know more.

Life cycle assessment for geothermal projects: general framework and GEOENVI guidelines

Life cycle assessment (LCA) is a structured, comprehensive method to quantify material and energy flows and their associated environmental performance occurring throughout the life cycle of a good and/or service.

The ILCD Handbook of the Joint Research Centre[1] and the ISO 14040-14044[2] standards provide the methodological references for LCA assessments. However, they represent a general framework not addressing any specific technological sector. Indeed, such very general guidelines leaves the user with a large range of choices resulting in a large variability in the LCA results that can affect their understanding by decision makers.

Motivation	• To offer guidance for **consistency, balance and quality Life Cycle Assessment** (LCA) • To enhance the **credibility** of the findings from LCAs on geothermal systems. • The guidelines 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.** • To provide guidance on **how and what to document** 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 pretend 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.

[1] European Commission. International Reference Life Cycle Data System (ILCD) Handbook: Framework and Requirements for Life Cycle Impact Assessment Models and Indicators; European Union: Luxembourg, 2010; ISBN 9789279175398.

[2] ISO. International Organization for Standardization ISO 14040:2006—Environmental Management—Life Cycle Assessment—Principles and Framework 2006;
ISO: Geneva, Switzerland, 2006. ISO. International Organization for Standardization ISO 14044:2006 Environmental Management—Life Cycle Assessment—Requirements and Guidelines 2006; ISO: Geneva, Switzerland, 2006.

GEOENVI developed LCA Guidelines for Geothermal Installations, intended to offer methodological indications and assistance on how to perform LCAs of geothermal systems.
The scope is to provide a common and accepted basis to evaluate the life cycle environmental impacts of geothermal energy systems to compare results for different geothermal settings and energy conversion technologies.
The guidelines include practical recommendations to support choices and assumptions needed to conduct the four phases of LCA according to ISO 14040 standards, namely Goal and scope definition; Inventory analysis; Impact assessment; and Interpretation.

Useful documents

- LCA Guidelines for geothermal installations: https://www.geoenvi.eu/publications/lca-guidelines-for-geothermal-installations/
- Panorama of sustainability studies for geothermal systems: https://www.geoenvi.eu/publications/panorama-of-sustainability-studies-for-geothermal-systems/

Simplified models

The European project GEOENVI developed **simplified models** to estimate the environmental impacts for a selection of four different types of geothermal installations over their life cycle:

- **Combined Heat and Power** (CHP) geothermal plant with low direct emissions
- **Enhanced Geothermal Systems** (EGS) for heat generation with very low direct emissions
- **Geothermal flash power plant** producing electricity and a limited amount of heat from a geothermal source with moderate to high content of NCGs, composed mostly of CO_2
- **Heat production plant including a demonstration Organic Ranking Cycle** (ORC), producing electricity for self-consumption with very low emissions

Simplified models – one per each environmental impact – are simple equations relying on a small number of variable parameters that allow environmental assessments of geothermal installations. According to LCA guidelines for geothermal installations (Blanc et al., 2020), seven simplified models per each of the four types of geothermal installation were developed, describing impacts on: **climate change**, **freshwater ecotoxicity**, **freshwater** and **terrestrial acidification**, **mineral** and **metal resource depletion**, **fossil resource depletion**, **human non-carcinogenic effects** and **human carcinogenic effects**. Each model relied on two to six most influencing variable parameters specific to the geothermal installation and explaining around 75% or more of the variance observed category.

Due to the modelling choices, GEOENVI simplified models are applicable only within a certain range of the variable parameters and after consideration of the fixed parameters. It is therefore essential to carefully check the applicability domain of each simplified model prior to using them for other geothermal installations.

The generation of these simplified models was possible thanks to the application of a **protocol**.

Why simplified models?

- LCA is time and data consuming
- Stakeholders are not LCA experts
- A new approach/protocol is currently available to produce simplified models based on LCA modelling
- Its application to GEOENVI case studies is currently being tested (Nov. 2020) and first simplified models are reported

- A simplified model for each impact category → set of simplified models to describe different environmental impacts
- A range of operation and type of geothermal system per set of simplified models

Motivation	• To offer very simple tools to facilitate and speed access to life cycle assessment for geothermal installations • To enlarge the simple vision of a single carbon footprint assessment for a multicriteria vision
Beneficiary	• **Decision makers** • **Non LCA practitioners**
Objective	• To provide life cycle environmental impact indicators with a very limited number of input variables (< 10) • To provide environmental assessment for a selection of Representative Geothermal System (RGS)
Scope	• These simplified models can only be used in accordance to the scope for which they have been designed for. • They are valid for specific technological ranges

Protocol for simplified models

The concept of the protocol was initially developed to produce simplified models for wind turbines (Padey et al., 2013) and for a first type of geothermal installation, an enhanced geothermal systems (EGS) plant generating electricity (Lacirignola et al., 2015). In GEOENVI it has been adapted to better account for uncertainty and variability sources in the environmental impact assessment of different geothermal installations.

This protocol enables users to generate simplified models for an extended set of geothermal installations categories, beyond the four already generated within the GEOENVI project.

Table 2 – Description of the categories of geothermal installations analysed to generate the reference LCA models from which simplified models are derived. RGS stands for representative geothermal system.

	EGS	Flash	CHP	HeatORC
RGS	Rittershoffen (FR)	Bagnore (IT)	Hellisheidi (IS)	Balmatt (BE)
Installed capacity of the RGS	27 MWth	61 MWe 21.1 MWth	303.3 MWe 133 MWth	6.6 MWth 0.25 MWe
Geothermal source type	Liquid	Vapour	Liquid/Vapour	Liquid
Production technology	Downhole pumps	Self-Flowing	Self-Flowing	Downhole pumps
Power/Heat generation unit	Heat exchanger	Flash steam plant	Double flash, Combined heat and power plant	Binary / Heat exchanger
Cooling system	None	Wet cooling tower	Wet cooling tower	Air cooling tower
Gas control system	None	NCG abatement system	None	None
Stimulation	Hydraulic-Thermal-Chemical	None	None	Chemical
Final energy use	Industrial heat	Electricity + Industrial heat	Electricity + Heat	Heat (+ Electricity for self-consumption)
Cluster in (Rocco et al., 2020)	2DHC	3P CHP	1P CHP	7P CHP

- This table can be found in D3.4 “Generation of simplified parametrised models for a selection of GEOENVI geothermal installations categories”

Steps of the protocol

The protocol is structured in 5 steps:

(1) definition of the **scope of the study**

(2) modelling and validation of a **reference LCA model**

(3) statistical process to identify the **key input variable parameters** for each impact category

(4) generation and validation of the **simplified models per environmental impact category**

(5) **Applicability domain** of the simplified models & optional iterative adjustment of the scope of the study.

The key variable parameters used for the definition of the simplified models (step 3) are selected (a) by performing a Global Statistical Analysis (GSA) calculating the first order Sobol' indices from the set of stochastic scenarios derived with a Monte Carlo simulation of the

distribution functions of all variable parameters and (b) by choosing the ones covering a sufficient share of the variance of the considered environmental impact quantified when running the reference LCA model (at least 75-80%). To ease the application of the protocol, in particular steps 3 and 4, the use of the open access libraries (based on Python language) Brightway2 (Mutel, 2017) and a dedicated library lca_algebraic (Jolivet et al., 2020) is recommended.

For geothermal installations, it is proposed to focus the generation of the simplified models on **the seven key impacts recommended by the LCA guidelines** for geothermal installations (Blanc et al., 2020) listed above.

It is worth underlining that for the same geothermal installation category, the set of influencing variable parameters might vary depending on the environmental impact. The LCA guidelines for geothermal installations recommend the use of the Environmental Footprint (EF) v3.0 (Fazio et al., 2018). However, given the current lack of implementation of the EF v3.0 in the software used when issuing this report, the ILCD 2018 impact categories (European Commission and Joint Research Centre, 2010) as available in the most recent ecoinvent v3 (Bourgault G., 2019) combined with the ecoinvent database v3.6 had to be used instead, despite the fact that it does not comply with the guidelines.

The definition of the applicability domain for the simplified models along the first and last step of the protocol is a critical point when applying the protocol. The user of the simplified models will be urged to carefully check the applicability domain of each simplified model prior to using it for their geothermal installations.

Finally, it is important to underline that the use of these simplified models does not replace thorough LCAs of geothermal installations but certainly gives first estimates of their environmental performances, whenever time or resources are lacking to conduct full LCAs.

Useful documents

- Generation of simplified parametrised models for a selection of GEOENVI geothermal installations categories > https://www.geoenvi.eu/publications/generation-of-simplified-parametrised-models-for-a-selection-of-geoenvi-geothermal-installations-categories/
- Elaboration of a general protocol to generate simplified models for geothermal installations > https://www.geoenvi.eu/publications/elaboration-of-a-general-protocol-to-generate-simplified-models-for-geothermal-installations/

Online resources

To know more about the training sessions, please visit the GEOENVI website: https://www.geoenvi.eu/events/
Please find here the recording of the GEOENVI webinar: How to simplify Life Cycle Assessment in deep geothermal projects with GEOENVI tool: https://youtu.be/Roz-lvxW5e8

Please find here the video tutorial to generate LCA simplified models for geothermal systems > https://youtu.be/kZHB--NFe50

Find here the Jupyter script of the video tutorial to generate simplified models and check out the links in the script > https://www.geoenvi.eu/wp-content/uploads/2020/11/ProtocolSimplifiedModels_vF_Jupiter-script.html

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