Harmonized Life Cycle Assessment Guidelines for geothermal installations

Feedback on the use of the harmonized guidelines and the protocol to generate simplified models

Deliverable number: (D.3.6)

Author(s): M. Douziech[(1)], I. Blanc[(1)], L. Damen[(2)], D. Fiaschi[(3)], V. Harcouët-Menou[(2)], G. Manfrida[(3)], B. Mendecka[(3)], M.L. Parisi[(3)], P. Perez Lopez[(1)], G. Ravier[(4)], L. Tosti[(3)]

Author'(s') affiliation: [(1)] MINES ParisTech / ARMINES, [(2)] VITO, [(3)] CSGI, [(4)] ES-Géothermie

The sole responsibility of this publication lies with the author. The European Union is not responsible for any use that may be made of the information contained therein. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No [818242 — GEOENVI]

GEOENVI

Executive summary

National workshops were held in the six partner countries of the GEOENVI project to present and promote the use of the developed Life Cycle Assessment (LCA) tools. These tools encompass guidelines to ease the application of LCA to deep geothermal systems and a set of simplified models that allow for quick and multi-criteria environmental impact assessments of specific types of geothermal installations. The methodology to generate these simplified models was also formalised as a protocol, whose dissemination is ensured through the deployment of a YouTube video and training seminars held within each GEOENVI partner country. The national workshops presenting the GEOENVI LCA tools met with great interest and enthusiasm with participant numbers ranging up to 55 and demands for additional and/or more in-depth (physical) meetings. In addition, many participants expressed their readiness to apply the GEOENVI LCA tools. A questionnaire was also sent out to the participants to gather feedback on the applicability of the developed LCA tools. The results of this questionnaire are summarised in this deliverable, focusing on the applicability of the LCA guidelines. Recommendations for a potential revision of the published guidelines are then presented. These recommendations result from the combination of the national workshop's feedback and the experience gathered during the application of the LCA guidelines to six case studies of the partner countries (D3.3.). In summary, while the current version of the guidelines is already regarded as very useful to help the application of LCA to deep geothermal systems, a future version of the guidelines could provide more information on or rephrase (1) the prioritisation of the impact categories, (2) the allocation method, (3) the system boundaries, and (4) the consideration of direct emissions.

Table of Contents

List of Figures

General Introduction

Conducting the Life Cycle Assessment (LCA) of a geothermal energy system requires a thorough knowledge of the geothermal installation itself as well as a good understanding of the LCA methodology. Life Cycle Assessment is a standardised, holistic, and multi-criteria method to estimate the environmental impacts of a system or product throughout its entire life cycle. It consists of four different steps as displayed in Figure 1.

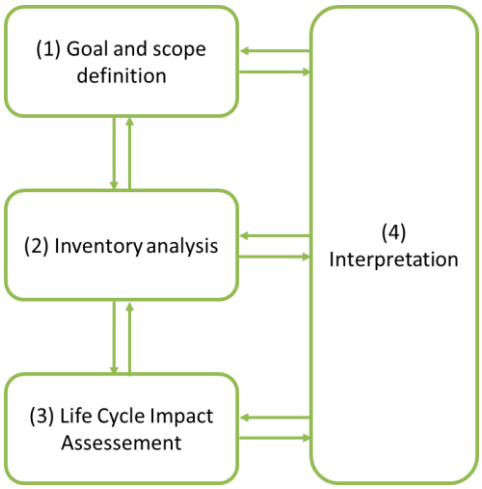

Figure 1 – Four stages of life cycle assessment as standardised in the ISO-Norms 14040 and 14044

Each step is clearly defined in the ISO-norms 14040 and 14044 and the Joint Research Centre also provides recommendations on this framework (European Commission and Joint Research Centre, 2010; ISO 14040, 2006). These recommendations are, however, general and leave the LCA practitioners with a number of choices when applying LCA to energy pathways. This results in large variation in published LCA studies of energy generating technologies, such as geothermal energy which can ultimately impact the confidence in LCA results and their use in decision-making processes (Eberle et al., 2017).

This observation was the starting point for the development of guidelines for the LCA of geothermal energy systems, published as D3.2. of the GEOENVI project in February 2020 (Blanc et al., 2020). The scope of these guidelines was to provide a first common support framework when conducting LCAs of deep geothermal systems. While defining LCA guidelines already contributes to ease the application of LCA to deep geothermal systems, conducting an LCA is still a complex and time-consuming task. As a result, the LCA experts of the GEOENVI project developed a set of simplified arithmetic equations to allow quick first multi-criteria environmental impact assessments of four types of geothermal installations. The application of these so-called simplified models only requires knowledge of a small number of parameters specific to the geothermal installation type considered and is accessible to non-LCA experts. Their generation, on the other hand, formalised through a protocol developed within the GEOENVI project, is not easily applied by non-LCA experts. Besides an excellent

understanding of the LCA methodology, applying the protocol also requires knowledge in the programming language Python. As a result, explaining how the protocol to generate simplified models should be used is not an easy task.

The dissemination of the GEOENVI LCA tools developed is essential to ensure they can be used to inform on the environmental performances of deep geothermal systems. The national workshops held in each partner countries throughout October and November 2020 were aimed at presenting in a concise and accessible way to non-LCA experts the developed GEOENVI LCA tools. Brief presentations were given on (1) the LCA guidelines, (2) the protocol to generate simplified models and (3) how the simplified models already developed by the GEOENVI partners can be applied. The expertise in LCA and programming available within each national team as well as the aim of reaching a broad audience was not compatible with a thorough description of the protocol's application. A hands-on session on the protocol was therefore not possible during the national workshops and feedback on its application was not gathered. Instead, to achieve a wider dissemination of the protocol, training material in the form of a YouTube video showing how to implement it in the Python programming language was recorded and is now available via the GEOENVI website (GEOENVI, 2020). The protocol is, in addition, also presented during follow-up training seminars in each project country.

Motivation and Objective

The LCA guidelines developed within the GEOENVI project and presented in D3.2. are a first attempt to provide support to LCA practitioners applying LCA to geothermal energy systems. Their development relied on a continuous exchange between geothermal and LCA experts and can therefore be seen as a reference in the field. Still, the applications of these guidelines and their presentation to an even wider audience of LCA and geothermal experts within national workshops were particularly useful to test their applicability and identify possible improvements. The objective of this deliverable is therefore to report on the feedback gathered during the national workshops on the use of the LCA guidelines. The feedback was collected using a questionnaire originally written in English (Appendix 1) and translated into the national language whenever necessary. The experiences made through the application of the guidelines to GEOENVI case studies are also reported here. A final list of recommendations for a future update of the guidelines is provided at the end of this deliverable.

Feedback on the guidelines for the Life Cycle Assessment of geothermal Installations

As mentioned in the introduction, feedback on the LCA guidelines was gathered during the different national workshops held in the partner countries. The questionnaire reported in Appendix 1 was used for this sake. The national workshops were held on the 30th of September in Iceland, 2nd of October in Turkey, 4th of November in Hungary and France, 5th of November in Italy and 16th of November in Belgium. In addition, the application of the LCA guidelines to the GEOENVI case study called for the clarification of some aspects of the LCA guidelines as described in the dedicated section. The attendees of the national workshops are summarised in Figure 1.

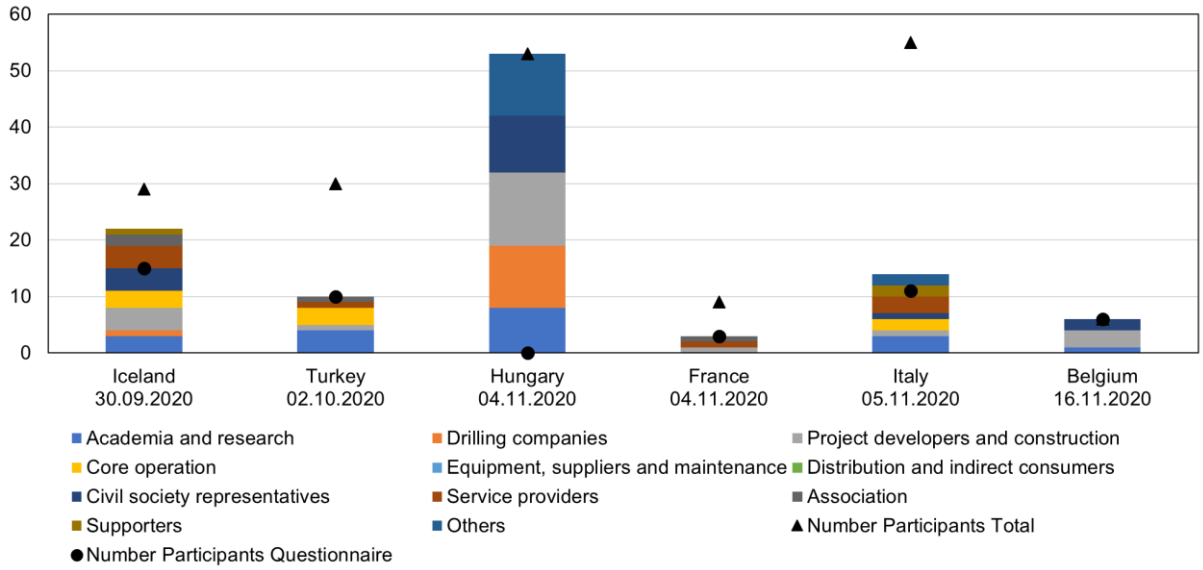

Figure 2 – Persons attending the national workshops, filling in the questionnaires and information on their field of work.

The answers to some questions particularly relevant with respect to the LCA guidelines are summarised in Figure 3.

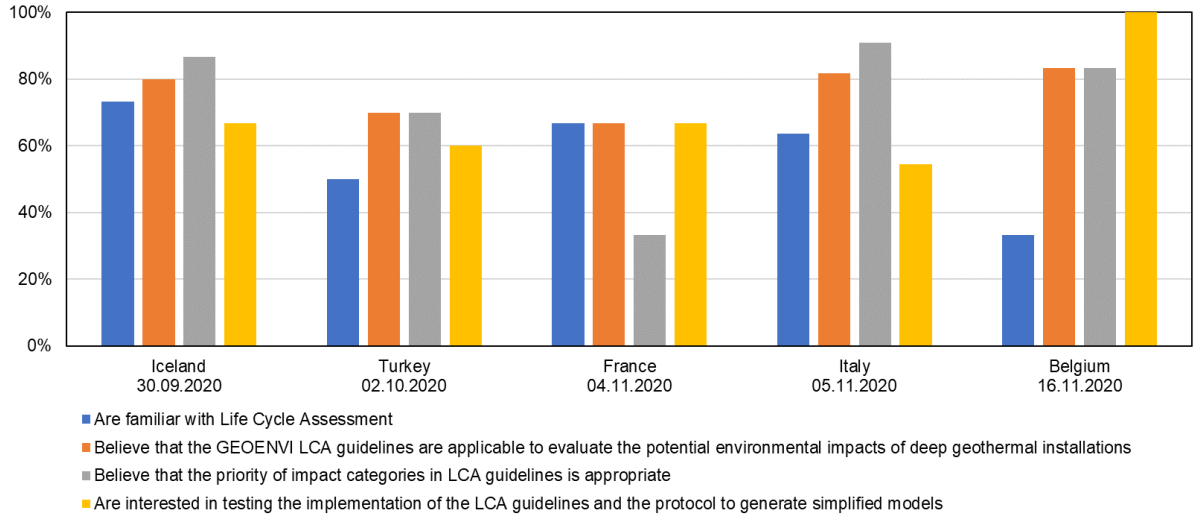

Figure 3 – Graphical representation of the answers to some questions of the national workshop's questionnaire particularly relevant with respect to the LCA guidelines.

National workshop In Iceland

The Icelandic national workshop held on the 30th of September 2020 involved 29 participants among which 15 filled in the questionnaire. Most of the participants had knowledge of LCA (11/15) and believed it is a useful tool to communicate the environmental performance of deep geothermal projects (13/15) and compare it to other energy generating technologies (12/15). Further, most of the participants found the developed LCA guidelines applicable to assess the environmental impacts of deep geothermal projects (13/15). While most of the participants (13/15) agreed with the selection of high priority environmental impact categories, one highlighted the importance of choosing the impact categories depending on the analysed case study. Finally, 10 out of the 15 answering participants were willing to participate in a process to test the adoption of LCA guidelines and the protocol on simplified models. Their main motivations were to better understand the environmental impacts related to deep geothermal installations and to support the ecodesign of the installations.

National workshop In Turkey

The Turkish national workshop held on the 2nd of October 2020 involved 30 participants among which ten filled in the questionnaire. Half of the participants were familiar with LCA and eight out of ten saw the potential of LCA to ease the communication of the environmental performance of deep geothermal systems and their comparison to other energy sources. A majority (seven out of ten) also believed that the developed LCA guidelines are applicable to assess the environmental impacts of deep geothermal installations but were concerned that

the LCA guidelines were not detailed enough. Another comment mentioned the need to extend the system boundaries to include applications that might impact the results such as the use of the CO_2 produced. Seven out of the ten people answering the questionnaire agreed with the priority level of the impact categories. Some commented, however, that all impact categories should be considered, mentioning especially the importance of photochemical ozone formation. Another important point raised was the need for guidance concerning the normalisation and weighting of the results. Differences in the choice of the weighting scheme depending on the level of development of the country were also highlighted. Four out of the ten respondents were interested in participating in a process to test the adoption of LCA guidelines and the protocol on simplified models, mostly to be able to compare the outcomes to other projects. Overall, some participants found the workshop too technical, but many of them also highlighted its relevance and wished to see it re-conducted as soon as face-to-face meetings become possible again to attract a wider audience. The wish for a training session showing how to apply the guidelines in LCA software such as OpenLCA was also expressed.

National workshop In Hungary

The Hungarian national workshop was held on the 4th of November 2020 (online) with 53 participants (academia – eight, SME/consultant - 13, ministry – two, authority – five, geological survey – 11, municipality – three, other – 11). The workshop was held together with the WP4 national workshop on recommendations for the harmonization of environmental regulations for deep geothermal systems. LCA is a very novel topic in Hungary, so that the interest in the developed tools and the expertise was very limited, although detailed presentations were provided on the LCA guidelines, case studies, as well as the simplified protocol and its applicability. No participant provided exact feedback, or expressed their interest in applying the LCA guidelines or simplified protocol to one of their projects. The lack of interest is also explained by the Hungarian geothermal market characteristics: there is no power plant, and although the direct use is significant, apart from three large district heating projects, most of the current uses are represented by small-scale agriculture users (greenhouse heating) and individual space heating associated by balneological sites. Nevertheless, there was some interest in the LCA methodology from academic participants, as a potential and new research field.

National workshop in France

The French national workshop was held on the 4th of November 2020 for nine participants, among which only three answered the questionnaire. Two participants were familiar with LCA

and all agreed that LCA was useful to communicate and compare the environmental performance of deep geothermal systems to other energy generating technologies. The respondents did see the potential of the developed LCA guidelines to assess the environmental performance of deep geothermal systems but also highlighted the need for a clear distinction between all types of geothermal installations and a better homogenisation of the recommended allocation methods. Such recommendations were linked to the FEDENE (FEDENE and SNCU, 2018) and the RE2020 (Groupe d'expertise 14, 2019). The allocation procedure recommended in the guidelines was also discussed because of a lack of clarity on the property used to compute the shares between electricity and heat. Another improvement point mentioned was related to the prioritisation of the impact assessment categories. It was highlighted that the particulate matter formation had to be considered in some cases and suggested to base the prioritisation scheme on the approach advocated by the JRC. This approach relies on normalisation and weighting to identify the impact categories contributing to 80% of the impact and focus the report on those. Similarly to the other workshops, the participants expressed their interest in applying the guidelines to compare the environmental performance of deep geothermal systems to other systems and develop arguments in favour of the deployment of this technology. The participants were overall happy with the workshop but wished for more time for exchanges and a better balance between the techniques presented and the state-of-the-art.

National workshop in Italy

The Italian national workshop was held on the 5th of November 2020 with 55 participants and 11 answering the questionnaire. Seven participants were familiar with LCA and the majority (eight) believed that LCA is a useful tool to communicate the environmental performance and improve the social acceptance of deep geothermal systems and also to compare the environmental performance of deep geothermal systems to other energy sources (9/11). Overall, nine of the people answering the questionnaire also believed that the guidelines could be used to assess the environmental performance of deep geothermal systems. Some criticism was however expressed concerning (1) the recommendation of the Environmental Footprint (EF) database, (2) the need for an impartial way to list the environmental impacts in list of importance and highlight the main negative and positive effects of a geothermal project, and (3) the focus on high enthalpy geothermal despite the potential need of LCA guidelines for geothermal projects having different mining and technological objectives. The second point was taken up again in the question on the proposed priorities of the impact categories, where despite 10 participants agreeing on the proposed priorities, one expressed the wish of a synthetic index showing the "global acceptance" of the entire geothermal project based on a

large set of priorities encompassing local and national components of the society, economy, and sustainability. Six respondents would be interested in applying the LCA guidelines. Overall, the participants were satisfied with the workshop but several respondents would have liked to see a more detailed, practical application of the developed tools. Also, the dissemination to a wider audience, and ideally in presence, was also mentioned as a potential improvement. Questions about the use of the project outcome by authorities were also raised.

National workshop in Belgium

The Belgian national workshop was held on the 16th of November 2020 with six participants who all answered the questionnaire. Only two participants were already familiar with LCA while the rest of the participants was not, but still the majority (five out of six) considered that LCA was useful to communicate the environmental performance of deep geothermal systems and increase their social acceptance. One participant expressed his/her concerns on the use of LCA after the plant already being in operation as the LCA results could not prevent or mitigate critical issues. Three participants doubt whether LCA can be used to compare the environmental performance of deep geothermal systems to other energy generating technologies, highlighting for example that currently not enough LCA studies were available to have a complete and fair overview of the environmental performances of geothermal systems as a whole. In addition, the participants wondered if one can guarantee that the systems compared are actually considering comparable extents. Still, five participants believed that the LCA guidelines were appropriate to assess the environmental performance of deep geothermal systems, one did neither agree nor disagree. The recommendations from the guidelines were deemed clear except for the allocation method, where the quantity used to differentiate the different cases of allocation was not clear. All participants expressed their interest in applying the LCA guidelines to their projects. Overall, the participants were satisfied with the workshop but four questioned the dissemination of the event, asking why only six participants attended the event.

Application of the guidelines to GEOENVI case studies by the GEOENVI partners

Applying the guidelines to the six case studies of Bagnore (IT), Rittershoffen (FR), Hellisheidi (IS), Balmatt (BE), a demonstration plant in Hungary, and Dora-II (TK) identified a couple of points that needed clarification. The main difficulty lies in the use of the EF v3.0 methodology, which is not available in current LCA software. On the contrary, the EF v2.0 is available in OpenLCA (Ciroth, 2007) but requires a conversion to EF v3.0 using the programmes available on the European Commission's website (Joint Research Centre, 2020). This conversion is cumbersome and prone to errors, making its use difficult at the present state. In addition to the technical difficulties, using the EF v3.0 implies the use of the corresponding database. While this database is free, it is currently less comprehensive than other commonly used databases such as ecoinvent (Ecoinvent, 2014), although this may evolve in coming years. Overall, the EF v3.0 methodology encompasses the most up to date impact assessment methods. The LCA practitioner should therefore strive to use this methodology, whenever possible. Given the current limited availability of the method in LCA tools, deviations from this recommendation are however possible. The use of the ILCD 2018 v2.0 method until the full version of the EF v3.0 method is made accessible on the common platforms is hereby an acceptable alternative and could be mentioned in the guidelines.

Another potential improvement of the LCA guidelines relates to the categorisation of the impact categories into high and low priorities. It was suggested that, in some cases, prioritisation may differ from the one of the guidelines. We propose a strategy to account for this in the next chapter.

Finally, applying the guidelines to the Bagnore plant in Italy showed the importance of direct, natural emissions on the LCA result. Current LCA methodologies do not sufficiently reflect the added value of geothermal plants in reducing H2S and Hg emissions compared to the natural state, but instead put the focus on the natural greenhouse gas emissions occurring during exploitation.

Recommendations for an update of the LCA guidelines for geothermal energy systems

The different national workshops as well as the application of the guidelines to six GEOENVI case studies all led to comments about the choice of the impact categories to be reported. The corresponding recommendations are listed below. In addition, questions were raised about the recommended allocation scheme and the compatibility with other approaches recommended by different organisms. The choice of the system boundaries was also questioned, especially with respect to the inclusion of relevant systems such as heat pumps or installations using the CO_2 produced and other co-products such as metals.

- Choice of the impact categories

In order to accommodate all the comments made on the recommendations of the LCA guidelines on the impact categories, we propose a three steps approach to be included in a potential revision of the guidelines. First, all impact category results should be reported in a table in the main text. Second, the choice of the discussed impact category results should be left to the LCA practitioner depending on geographical and technological specificities. Finally, in some cases normalization and weighting could be applied to ease the communication of the results. While recommending a normalisation and weighting scheme for deep geothermal projects is beyond the scope of these guidelines, the application of the most up to date weighting and normalisation scheme presented by the Joint Research Centre for the EF methodology is an option for practitioners deeming it useful (Sala et al., 2018).

- Allocation

The proposed approach enables to deal with plants that co-produce heat and electricity using allocation when necessary. It differentiates whether the installation is producing mainly heat or electricity to avoid allocation. When the co-products are produced in similar amounts, the approach suggests allocation using exergy. This differentiation is based on the ratio of the total energy produced, which might require a clearer statement in the published LCA guidelines. This limits the computation of negative environmental impact results and their difficult interpretation. It can however be questioned for cases at the limits of the set boundary of 25%. In addition, it is difficult to apply the approach for geothermal installations producing other products such as minerals and liquid/gas (e.g. lithium, boron, methane...). The discussion on the system boundaries might help to answer this issue by suggesting to only include in the core systems the installations producing heat and/or electricity and thus not the ones used for lithium extraction. Overall, it would be ideal for the scientific community to agree on a common allocation approach applicable to any energy type to ensure fair comparison between energy

systems. This was, however, beyond the scope of this project but should be given consideration in the future.

- System boundaries

The inclusion of “relevant processes” in the system boundaries is a difficult question to answer as it comes with the risk to render LCA results incomparable. In addition, it might increase the allocation issue as the system could produce additional outputs than heat and/or electricity. As a result, we recommend keeping the system boundaries to the upstream (background data) and core modules necessary to produce heat or electricity that can be used directly by the user while excluding the distribution to the end user. The heat pump that ensures a sufficient quality of the heat for the end user should therefore be included in this module but not the installation potentially post-processing other products of the system. The inventory necessary for the heat pump modelling should hereby be collected in a separate process, not covered by the guidelines for deep geothermal systems published within GEOENVI.

- Direct emissions

The first version of the guidelines states that the H_2S emissions should be multiplied by a factor 1.88 to estimate their mass equivalent in SO_2. This approach is necessary for impact category methods that do not include characterization factors for H_2S but not for EF v3.0 anymore, since a characterization factor for H_2S is available.

References

Blanc, I., Damen, L., Douziech, M., Fiaschi, D., Harcouët-Menou, V., Manfrida, G., Mendecka, B., Parisi, M.L., Pérez-López, P., Ravier, G., Tosti, L., 2020. LCA guidelines for geothermal installations. GEOENVI Project # 818242.

Ciroth, A., 2007. ICT for environment in life cycle applications openLCA — A new open source software for life cycle assessment. Int J Life Cycle Assess 12, 209. https://doi.org/10.1065/lca2007.06.337

Eberle, A., Heath, G.A., Carpenter Petri, A.C., Nicholson, S.R., 2017. Systematic Review of Life Cycle Greenhouse Gas Emissions from Geothermal Electricity (No. NREL/TP--6A20-68474, 1398245). https://doi.org/10.2172/1398245

Ecoinvent, 2014. Documentation of electricity mix of different countries [WWW Document]. Forum for ecoinvent version 3. URL https://www.ecoinvent.org/support/ecoinvent-forum/topic.html?&tid=106 (accessed 5.12.20).

European Commission, Joint Research Centre, 2010. ILCD handbook: general guide for life cycle assessment : detailed guidance. Publications Office of the European Union, Luxembourg.

FEDENE, SNCU, 2018. Enquête nationale sur les réseaux de chaleur.

GEOENVI, 2020. LCA Tools [WWW Document]. GEOENVI. URL https://www.geoenvi.eu/lca-for-geothermal/

Groupe d'expertise 14, 2019. Préparation de la RE2020 - GE14 - Modalités de prise en compte des innovation.

ISO 14040, 2006. ISO 14040:2006. International Organization for Standardization.

Joint Research Centre, 2020. European Platform on Life Cycle Assessment - Developer [WWW Document]. Developer. URL https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml (accessed 11.13.20).

Sala, S., Kim Cerutti, A., Pant, R., 2018. Development of a weighting approach for the Environmental Footprint (No. EUR 28562 EN). Joint Research Center.

Appendix 1 - Questionnaire sent out to the participants to the national workshops

QUESTIONNAIRE FOR TASK 3.4 NATIONAL WORKSHOPS WITH STAKEHOLDERS

Family name _____ Name _____

Name of the company/institution _____

1) To which of the following categories of stakeholder do you belong?

- ☐ 1) Academia and research
- ☐ 2) Drilling companies
- ☐ 3) Project developers and construction
- ☐ 4) Core operation
- ☐ 5) Equipment, suppliers and maintenance
- ☐ 6) Distribution and indirect consumers
- ☐ 7) Civil society representatives
- ☐ 8) Service providers
- ☐ 9) Associations
- ☐ 10) Supporters

2) Do you already know the LCA (Life Cycle Assessment) methodology for the evaluation of the potential environmental impacts of products and services?

☐ YES ☐ NOT

If you answered YES, please describe briefly which are your main experiences with the LCA methodology and its application

_____

3) The adoption of the LCA approach allows to identify, mitigate and eventually prevent critical issues potentially arising during the whole life cycle of a deep geothermal project and consequently find solutions for environmental performance improvement.

Please provide a vote, from 1 to 5

I do not agree ☐ 1 ☐ 2 ☐ 3 ☐ 4 I fully agree ☐ 5

4) The adoption of the LCA approach is important to better communicate environmental performances of facilities and improve the social acceptance towards deep geothermal projects

Please provide a vote, from 1 to 5

I do not agree ☐ 1 ☐ 2 ☐ 3 ☐ 4 I fully agree ☐ 5

5) The LCA methodology allows to effectively compare the environmental performances of deep geothermal resources with other energy sources (renewables or not)

Please provide a vote, from 1 to 5

I do not agree ☐ 1 ☐ 2 ☐ 3 ☐ 4 I fully agree ☐ 5

6) Do you think GEOENVI LCA guidelines are applicable to evaluate potential environmental impacts of deep geothermal installations?

Please express your opinion from 1 to 5

They are not applicable to this kind of projects ☐ 1 ☐ 2 ☐ 3 ☐ 4 They are fully applicable to this kind of projects ☐ 5

How would you improve GEOENVI LCA guidelines for deep geothermal?

_____

7) Do you think that priority of impact categories (climate change total, freshwater ecotoxicity, freshwater and terrestrial acidification, mineral and metal resource depletion, fossil resource depletion, human non-carcinogenic effects, human carcinogenic effects) proposed in the GEOENVI LCA guidelines is appropriate?

Please express your opinion from 1 to 5

The proposed priority of impact categories is not appropriate ☐ 1 ☐ 2 ☐ 3 ☐ 4 The proposed priority of impact categories is fully appropriate ☐ 5

How would you update priority of impact categories in GEOENVI LCA guidelines for deep geothermal?

---

8) Are the GEOENVI simplified models easy to apply by non-LCA experts, to estimate the environmental life cycle impacts of a deep geothermal project?

Please provide a vote, from 1 to 5

They are difficult to apply by non-LCA experts				They are easy to apply by non-LCA experts
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Please give reasons for your answer

---

9) Is your entity interested in testing the implementation of LCA guidelines and the protocol to generate simplified models for deep geothermal installations?

☐ YES ☐ NOT

If you answered YES, please explain what do you expect from the adoption of guidelines and protocol for your deep geothermal project

---

10) Is your entity interested in being committed in a process, supported by GEOENVI partners, to test Project's LCA simplified models generated for deep geothermal installations, after a dedicated training?

☐ YES ☐ NOT

11) What would you improve for a next workshop organized by the GEOENVI consortium on the same topic?

☐ a) dissemination of the event

☐ b) easier presentations for non-expert audiences

☐ c) more time for questions and answer session

☐ d) other (specify)

Please explain your answer:

_____

Appendix 2 - Overview of the answers to the questionnaire

First, the number of answers to the specific questions are summarized in followed by the detailed answers to some questions as reported by the participants to the different workshops.

Country	Iceland	Turkey	Hungary	France	Italy	Belgium
Date	30.09.2020	02.10.2020	04.11.2020	04.11.2020	05.11.2020	16.11.2020
Number Participants Total	29	30	53	9	55	6
Number Participants Questionnaire	15	10	0	3	11	6
Academia and research	*3*	4		0	3	1
Drilling companies	*1*	0		0	0	
Project developers and construction	*4*	1		1	1	3
Core operation	*3*	3		0	2	
Equipment, suppliers and maintenance	*0*	0		0	0	
Distribution and indirect consumers	*0*	0		0	0	
Civil society representatives	*4*	0		0	1	2
Service providers	*4*	1		1	3	
Association	*2*	1		1	0	
Supporters	*1*	0		0	2	
Others					2	
Knowing LCA	11	5		2	7	2
LCA useful for potential issues in LCA (strongly agree and agree counted)	13	7			11	5
	Rest neither agree/disagree	Rest neither agree/disagree				1 does not agree
LCA useful to communicate environmental perfromance and improve social acceptance	13	8		3	8	5
	Rest neither agree/disagree	Rest neither agree/disagree			2 neither agree/disagree 1 does not agree	1 neither agree/disagree

LCA useful to compare environmental performance with other energy sources	12 Rest neither agree/disagree	8 Rest neither agree/disagree	3	9 2 neither agree/disagree	3 3 neither agree/disagree
LCA guidelines applicable to assess environmental impacts	12 Rest neither agree/disagree	7 2 neither agree/disagree 1 disagree	2 Rest neither agree/disagree	9 2 neither agree/disagree	5 1 neither agree/disagree
Priority of impact categories in LCA guidelines appropriate	13 Rest neither agree/disagree	7 2 neither agree/disagree 1 disagree	1	10 1 neither agree/disagree	5 1 neither agree/disagree
Application of simplified models easy for non-experts (only easy)	3 9 neither agree/disagree 1 difficult	0 9 neither agree/disagree 1 difficult/very difficult	2 1 neither agree/disagree	3 6 neither agree/disagree 2 disagree	5 1 neither agree/disagree
Interested in a process to apply guidelines and protocol to generate simplified models	10 Rest No	4 Rest No	2 Rest No	6 Rest No	6
Interested in a process to apply the simplified models		4	2	7	5

Written feedback from the national workshops

The adoption of the LCA approach allows to identify, mitigate and eventually prevent critical issues potentially arising during the whole life cycle of a deep geothermal project and consequently find solutions for environmental performance improvement.
Begium:

- The LCA approach if applied after the plant is already in operation will not allow to prevent or mitigate critical isses, especially technical issues that are not foreseen beforehands. For example, if the gas content is higher than expected and the mitigation measure is not sufficient to circumvent it completely then the LCA approach will not help.

The LCA methodology allows to effectively compare the environmental performances of deep geothermal resources with other energy sources (renewables or not)

Belgium:

- The number of geothermal plants and related LCA is not sufficient to make a fair comparison with other energy sources. The fact that each geothermal project has some site specificities also makes it difficult. More projects are needed to an effective comparison process.

Do you think GEOENVI LCA guidelines are applicable to evaluate potential environmental impacts of deep geothermal installations? If not, please provide some suggestions for improvement.

Turkey:

- System boundary extension to applications affecting results (use of CO2 produced) more understandable and applicable- involve more industrial stakeholders
- more detailed information
- normalisation and weighting

France

- Better distinction of the types of geothermal installations
- homogenise allocation methods (CHP foreseen in FEDENE)
- additional impact categories based on normalisation or weighting (similar to JRC approach)

Italy

- I am not yet sure about this, but I think that limiting the analysis to the use of EF database can be reductive. Maybe you could also take into account databases that are widely accepted as ecoinvent.
- I think that one of the priorities to be taken into account is a "guide for the evaluation of geothermal projects for public bodies and institutional financing parties", with the objective of informing and facilitating tasks of the bodies in charge of granting licenses:

1) I would define a standard method to list aspects in order of importance;
2) I would define in a rigorous/impartial way (for example with a numerical system), not subject to personal or emotional evaluations, the main negative and positive effects of a project (today this evaluation is too subject to the culture of denial and to long times);
3) I would sensitize public offices in charge towards a culture of RES, keeping them informed about the EU objectives towards the "zero carbon" strategy and steps to 2030 and 2050. The EU objectives must act as a priority evaluation guide for a project, according to precisely indicated and assigned themes;
4) these evaluation criteria must constitute an unique and compulsory methodology for all: proponents, bodies in charge of managing the assessment for a permit, who participates to decision making conferences, institutional lenders and banks.

- Maybe the simplified models reduce the qualitative impact of positive environmental indicators, because of their lower flexibility related to applicable technologies and of different characteristics of geothermal fluids

Do you think that priority of impact categories (climate change total, freshwater ecotoxicity, freshwater and terrestrial acidification, mineral and metal resource depletion, fossil resource depletion, human non-carcinogenic effects, human carcinogenic effects) proposed in the GEOENVI LCA guidelines is appropriate? How would you update priority of impact categories in GEOENVI LCA guidelines for deep geothermal?

Iceland

- very case dependent, accordingly addressed in guidelines (including categories not addressed in the question)

Turkey
- photochemical ozone generation
- all segmental priorities
- Weighting depending on the country (e.g. development conditions)

France
- use the PEF guidelines and normalise to only include the impact categories contributing to 80% of the total

Italy
- In addition to LCA, I also use emergetic analysis, from which I learned to adopt an holistic perspective, which would lead to look at all impact categories
- Synthetic index of ""global acceptance"" for the whole geothermal project: I suggest to establish a standard methodology, recognized by all for a synthetic (and indisputable) quantification of a single numerical reference parameter, which expresses the sum of all weighted impacts (positive and negative) of a geothermal project, on the set of priority local and national components: environmental, economic, employment, social, coherence with circular economy, development of related and new satellite activities, adherence to strategic guidelines declared in EU documents, etc.
- I feel that effects on human health should have more weight, especially if results are used for the communication outside. It seems that local communities are interested to these impacts.

Are the GEOENVI simplified models easy to apply by non-LCA experts, to estimate the environmental life cycle impacts of a deep geothermal project? Please give reasons for your answer

Turkey
- backing up and sharing statistical data
- variables hard to obtain
- level of education should be sufficient

France
- not too many parameters, easy to gather

Italy
- I would like to better understand how simplified models work
- I have not yet tried this kind of tools.
- The method should also be easy to use by offices of public authorities in charge of issuing authorizations and by technical consultants of financial institutions.
- These models seem to be poorly flexible, event in relation to the high variability of geothermal fluids characteristics
- A simplified tool can be certainly of great help, also for non-LCA experts (as it could be me!). It is fundamental, in my opinion, to obtain shared guidelines, also with authorities in charge of carrying out EIA, in order to have a common, clear and shared procedure on how to prepare environmental impact assessments of geothermal projects. The ease in applying the method will be related to the availability of information and tools (e.g. software, etc.) possibly needed to use the methodology, as well as to the availability of a clear user manual
- Compex formula to understand
- to increase the use of graphical scoring descriptions on a scale
- my knowledge on LCA methods is not sufficient to provide suggestions

Is your entity interested in testing the implementation of LCA guidelines and the protocol to generate simplified models for deep geothermal installations? If you answered YES, please explain what do you expect from the adoption of guidelines and protocol for your deep geothermal project

Iceland
- better understanding of environmental impacts

- ecodesign

Turkey
- comparison with other projects

France
- comparison with other projects
- propose arguments in favor of geothermal energy
- evaluate all activities

Italy
- this model is calibrated on high enthalpy geothermal, but it might be worth considering models, more or less simplified, also for geothermal projects that have different mining and technological objectives

What would you improve for a next workshop organized by the GEOENVI consortium on the same topic?

Turkey
- not understandable enough by non-academia, simplify the presentations
- More participants (face-to-face meetings)
- training on OpenLCA/ LCA program

France
- better balance between techniques and current practices
- more time for exchanges

Italy
- to invite financial institutions- to describe a practical case of application- the initial approach must be concise- this first meeting has been useful for who is stranger of LCA analysis, but maybe too simplified to go into detail on the topic
- Funder are those that allow to start or not a geothermal project. Therefore, I think that they must be involved as a priority. Despite thery are not technicians, they have to be involved because they have perplexities and particular doubts often related to "non-technical" issues, which must be considered anyway and for which we have to find answers that give concretness and decision-making certainties in their board of directors. This will allow to pick up critical points of a weak and uninformed link of the decision-making chain, related to a geothermal project.
- The wider the audience, the greater the possibility of rising awareness and informing a greater number of subjects.
- The analysis of a practical case can be useful to understand the applicability or less of the procedure (in terms of availability of data, time needed for the application, etc.)
- more details with practical examples
- Researchers, mainly when they are affiliated to local implementation bodies, are among the most trustworthy sources for citizens.- Compatibly with the restrictions imposed by the current health crisis, it should be useful to replicate similar events (also) in physical presence, into areas more directly interested by themes addressd (in this sense, the Mount Amiata, with reference to data provided on Bagnore), trying to collaborate with municipalities and opening discussions for debate with civil society (e.g. environmental associations)
- not secondary purpose of an LCA is the dissemination, any popularizing action is of primary importance
- give the possibility to clarify aspects which are specific to their own experiences/needs

Belgium
- Dissemination of the event

Additional feedback

Italy
- What is the impact that this project could have on authorization procedures? May regional and/or ministerial authorities in charge ask proponents to provide this evaluation?

- What are results in terms of use of LCA outcomes for decision making of local governments or investors? For example, have you seen an increased use of comparative LCA, with other energy sources, to support investment choices?
- Do you think to deepen the concept of CO2 neutrality? Of course, geothermal CO2 is not produced during the plant operation
- Could we better clarify the choice of parameters for the simplified model? Temperature and productivity of wells are fundamental. How do you consider this into the three considered parameters?
- To consider the geothermal CO2 as the CO2 produced by thermoelectric power plants can be misleading. This should be clarified to avoid misunderstandings with stakeholders
- In case we consider the possibility of using LCA simplified models, what is their flexibility to be adapted to existing constant differences, also just in relation to the characteristics of geothermal fluids, which naturally differ among different areas?
- In case of ORC plants, what should we consider?

The sole responsibility of this publication lies with the author. The European Union is not responsible for any use that may be made of the information contained therein. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No [818242 — GEOENVI]