WP3 – LCA Litterature Review - Task 3.1
On going Task

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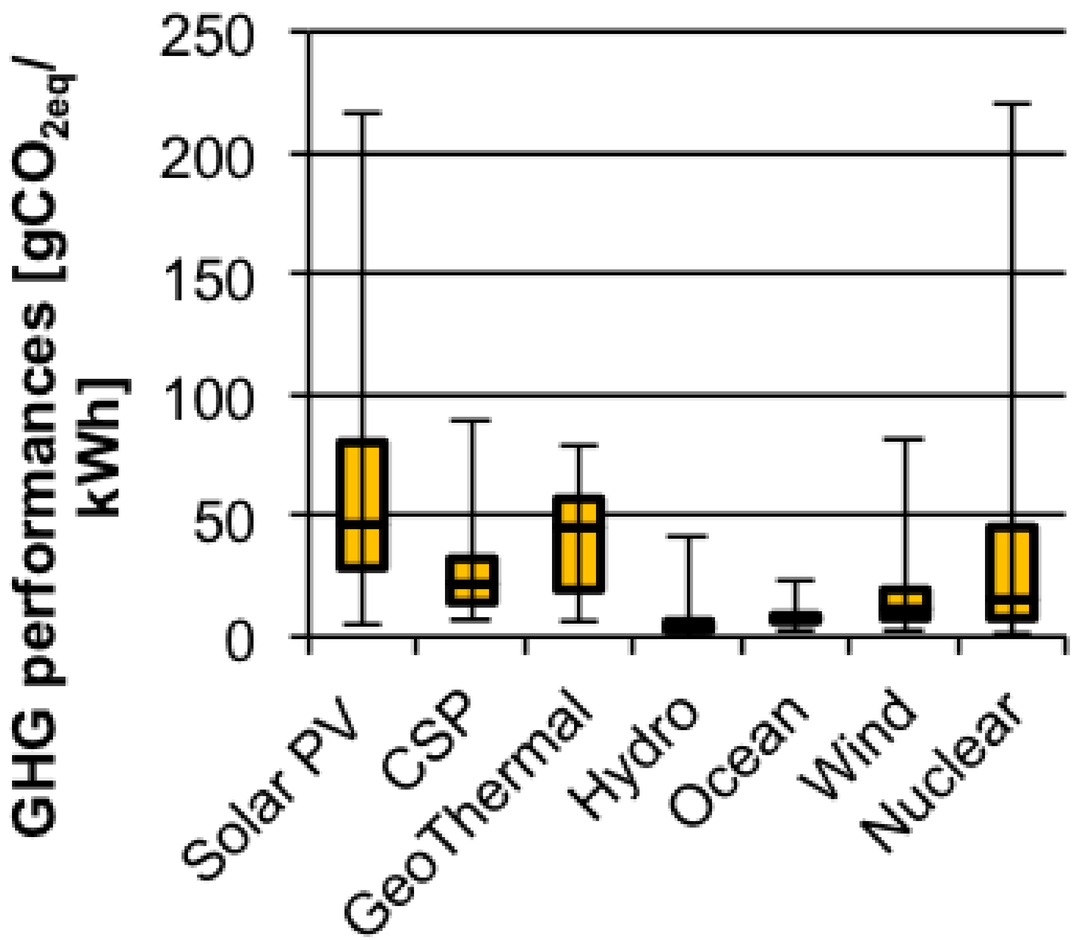
Laura Parisi, Barbara Mendecka
CSGI

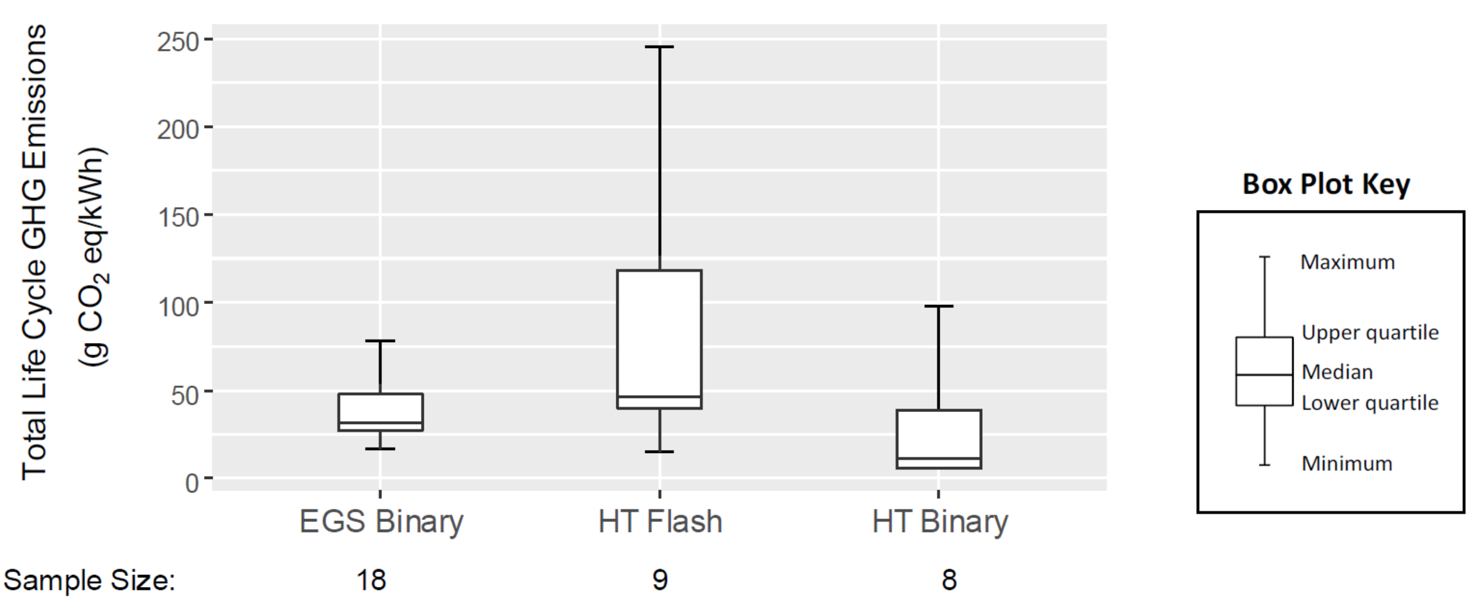
Carbon footprint of energy pathways



Source : IPCC 2011

IPCC 2011 Source: Moomaw, W., P. Burgherr, G. Heath, M. Lenzen, J. Nyboer, A. Verbruggen, 2011: Annex II: Methodology. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs- Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

NREL Panorama of LCA for geothermal systems carbon footprint



Type of geothermal systems	GHG in gCO_2eq/kWh Mediane estimate
Enhanced Geotherml System (EGS) Binary	32
Hydrothermal (HT) Flash	47
Hydrothermal (HT) Binary	11,3

26 LCA studies elligibles among 180 studies
(Harmonized method, Heath and Man, NREL, 2012)

Source: Systematic Review of Life Cycle Greenhouse Gas Emissions from Geothermal electricity, Eberle et al., NREL,Technical report NREL/TP-6A20-68474, september 2017.

Author of the synthesis	TITLE	AUTHORS	JOURNAL	YEAR	DOI/URL
CSGI - BM	Life cycle assessment of geothermal binary power plants using enhanced low-temperature reservoirs	Frick S, Kaltschmitt M, Schröder G.	Energy	2010	https://doi.org/10.1016/j.energy.2010.02.016
CSGI - BM	On the environmental suitability of high- and low-enthalpy geothermal systems	Martín-Gamboa M, Iribarren D, Dufour J.	Geotermics	2015	https://doi.org/10.1016/j.geothermics.2014.03.012
CSGI - BM	Review on life cycle environmental effects of geothermal power generation	Bayer P, Rybach L, Blum P, Brauchler R.	Renewable and Sustainable Energy Reviews	2013	https://doi.org/10.1016/j.rser.2013.05.039
CSGI - BM	Life cycle analysis of geothermal energy for power and transportation: A stochastic approach	Hanbury O, Vasquez VR.	Renewable Energy	2018	https://doi.org/10.1016/j.renene.2017.08.053
CSGI - BM	Life cycle assessment of geothermal power generation technologies: An updated review	Tomasini-Montenegro C, Santoyo-Castelazo E, Gujba H, Romero RJ, Santoyo E	Applied Thermal Engineering	2017	https://doi.org/10.1016/j.applthermaleng.2016.10.074
CSGI - BM	Life-cycle climate-change impact assessment of enhanced geothermal system plants in the Upper Rhine Valley	Pratiwi A, Ravier G, Genter A.	Geothermics	2018	https://doi.org/10.1016/j.renene.2012.08.005
CSGI - BM	Environmental impact of electricity from selected geothermal power plants in Italy	Bravi M., Bassosi R.	Journal of Cleaner Production	2014	https://doi.org/10.1016/j.jclepro.2016.11.024
ARMINES	Life cycle assessment of Organic Rankine Cycles for geothermal power generation considering low-GWP working fluid	Heberle F, Schifflechner C, Brüggemann D.	Geothermics	2016	https://doi.org/10.1016/j.geothermics.2018.03.012
ARMINES	Hybrid life cycle assessment of a geothermal plant: From physical to monetary inventory accounting	Martínez-Corona JI, Gibon T, Hertwich EG, Parra-Saldívar R.	Journal of Cleaner Production	2017	https://doi.org/10.1016/j.geothermics.2016.06.010

Geographical reference	Time boundaries	Specific scope	Env.Aspects	Details	Abatement
Germany	2006	III. LCA: environmental quantitative and qualitative data, data on potential environmental footprints	General aspects		
Europe		III. LCA: environmental quantitative and qualitative data, data on potential environmental footprints	General aspects		

Type of geothermal application		Technology electricity/CHP	Technology heat	Generator Type	Heat prodcution (CHP)
Electricity	Multifunctionality: CHP	Enhanced Geothermal Systems (EGS)		Binary	Series
Electricity	Heat	Enhanced Geothermal Systems (EGS)	Low enthalpy	Binary	not applied

(I) Goal definition/Intended application	(II) Goal definition/Intended application	Functional Unit	Multifunctionality approach & Type of allocation	Allocation description	System boundaries	System coverage	C
Comparative analysis of environmental impacts of geothermal systems		1 kWh electricity or 1 MJ heat	Allocation:exergy		cradle to grave		
Comparative analysis of environmental impacts of geothermal systems	Benchmarking against other technologies	1 MWh electricity or 1 MWh heat	not applied		cradle to gate		

Functional Unit	Multifunctionality approach & Type of allocation	Allocation description	System boundaries	System coverage	Cut off criteria	Availability of LCI
1 kWh electricity or 1 MJ heat	**Allocation:exergy**		**cradle to grave**		no info	**YES**
1 MWh electricity or 1 MWh heat	**not applied**		**cradle to gate**		no info	**YES**

LCIA methodology	Impact Categories	LCA Results	Database used fo background process modelling	LCIA results availability
Single Impact, Emission etc	**CO2 eq, SO2 eq, PO4 eq, CED**		**Ecoinvent**	**Single Score**
Single Impact, Emission etc	**ADP, GWP, ODP, POFP, AP, EP, CED**		**Ecoinvent**	**Single Score**

ower plant capacity, Mwel	Power plant capacity, MWth	Capacity Factor, % (full load hours/8670)	Plant lifetime, years	Estimated output - electric, MWh/year	Estimated output - heat, GJ/year
1,75	5.56/3.45	A1 7000/A2 6529/B1 7000/B2 6662 electric; A2 and B2 1800/1800 thermal	30	A1 6476/A2 6041/B1 7679/B2 7308	case A2: 22,349 GJ (heat) ; case B2: 3
2,9	0,1066	0,95890411	25/20	24360	

WHAT ARE THE TOOLS AVAILABLE FROM WP 3 ?

		PUBLIC TARGETED	Type of tools
D3.2 : *first version of LCA guidelines for geothermal systems*	M12 October 2019	LCA experts	« Paper » Method
D3.4: *Generation of the detailed LCAs & the simplified parameterized model for 7 ? case studies*	M18 April 2020	Decisions makers – non LCA experts	Simplified model ready to use for specific geothermal configurations
D3.5 *Elaboration of a general protocol to deliver simplified models for geothermal installations for environmental experts as a target*	M20 June 2020	LCA experts & Python expert able to generate new simplified models	Algorithm to be implemented in a code by the user

WP3 – Tools

ARMINES /

ENSMP=MINES ParisTech

Isabelle Blanc **Paula Perez-Lopez**

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SOPHIA Course in April 2019

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D3.4 : Generation of detailed LCA models & simplified models

	TEAM	Detailed LCA Model (linked with the CSGI questionnaire)	Simplified Model	Case studies
1	ARMINES/ ESG	I.Blanc / P. Perez Lopez / G Ravier	I.Blanc / P. Perez Lopez / G Ravier	EGS model (Soultz-sous-forêt)
2	ARMINES/ ESG	S. Angal / P. Perez Lopez / G. Ravier / I.BLanc	S. Angal / P. Perez Lopez / G. Ravier / I.BLanc	Rittershofen (ESG)
3	VITO	Lisa Damen (VITO)	Lisa Damen	Balmatt (VITO)
4	CSGI	Castel Nuovo Bagnore 3&4 –Laura & Barbara (CSGI)	Nicola Ferrara	Bagnore 3&4 Castelnuovo Italy
5				Hungary
6	OS	Valdimar Eggertsson (OS)	Valdimar Eggertsson (OS) Silvia Rakel (ISOR)	Hellisheidi Iceland
7			Use of the simplified model for validation	Turkey

GEOENVI

ADVANCED LCA METHODOLOGIES AND TOOLS: UNCERTAINTIES AND VARIABILITY

1th – 5th April 2019
MINES ParisTech, Sophia Antipolis (France)

Ph.D Course in April 2019

ORGANIZED BY ECOSD NETWORK

This course is primarily open to PhD students from institutions belonging to EcoSD network but also open to other researchers. is supervised by Pr. Isabelle Blanc, administrator of EcoSD and professor at MINES ParisTech.

MINES ParisTech | PSL | Réseau EcoSD Eco-conception de systèmes durables | IFSTTAR

How it works to generate a parametrized simplified model ?

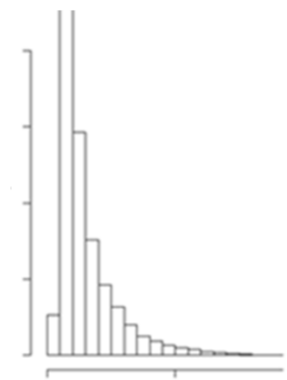
Step 1

Scope of the study

- **Study objectives , goal and scope**
- **Variability sources identification**
- **General assumptions**

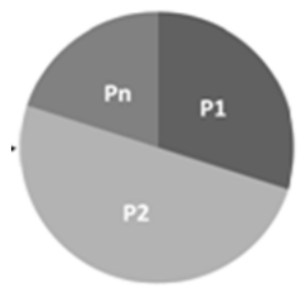
Step 2

Explicit Reference LCA model



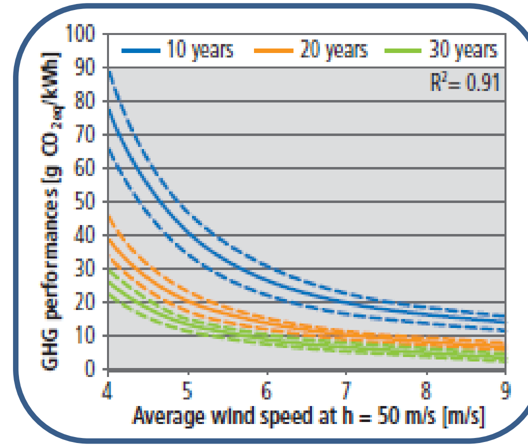
Step 3

Statistical Selection of key parameters by GSA(*)



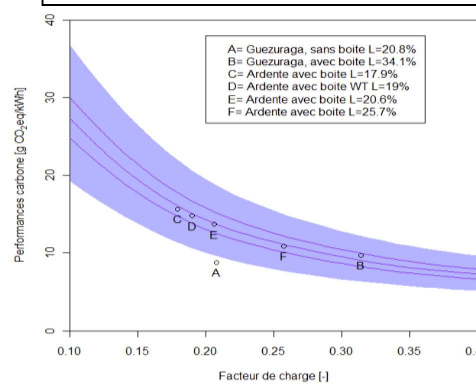
Step 4

Regression model = reduced parameterized model



Step 5

Simplified model compared with literature



Redefinition of the scope of the study

From Padey, P.; Girard, R.; le Boulch, D.; Blanc, I. From LCAs to Simplified Models: A Generic Methodology Applied to Wind Power Electricity. *Environmental Science & Technology* **2013**.

(*)GSA = Global Sensitivity Analysis

Methodology applied to EGS systems (Soultz sous forêt)

1. Lifecycle input/output data list (to be upscaled)

2. Selection of relevant input variables for a generic EGS LCA model

3. Design* of a **reference** parameterized model:
$GHG_{EGS} = f$ (depth, nb.wells, flow rate, fuel for drilling, life time, ORC capacity, enhancement scaling factor, load factor, pump power)

9 input parameters

Application of Global Sensitivity Analysis

4. Design of a **simplified** parameterized model:
$GHG_{EGS} = f$ (depth, nb.wells, flow rate)

2-3 key parameters

(*) *Lacirignola M, Hage Meany B, Padey P and Blanc I: A simplified model for the estimation of life-cycle greenhouse gases emissions of enhanced geothermal systems,* ***Geothermal energy*** *(2014), 2:8*

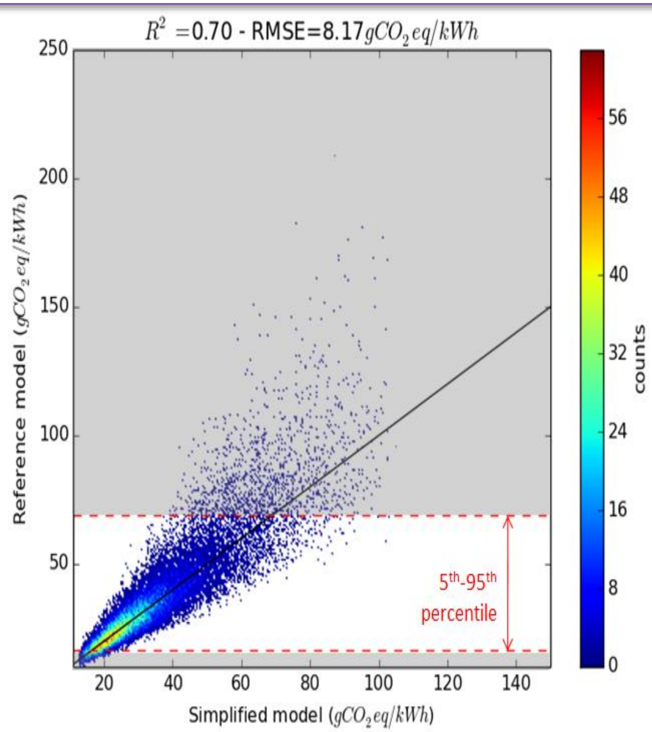
D3.4 : Design of a simplified parameterized model for EGS (case study 1)

From *f(9 variables)* → *ϕ(3 variables)* : installed capacity, nb. wells and borehole depth

Simplified model formula (3-variables):

$$GHG_{EGS\_Simpl3} = f(P_{ORC}, z, Nw) = \frac{Nw \cdot (\beta_1 \cdot z + \beta_2) + \beta_3 \cdot P_{ORC} + \beta_4}{P_{ORC} - \beta_5}$$

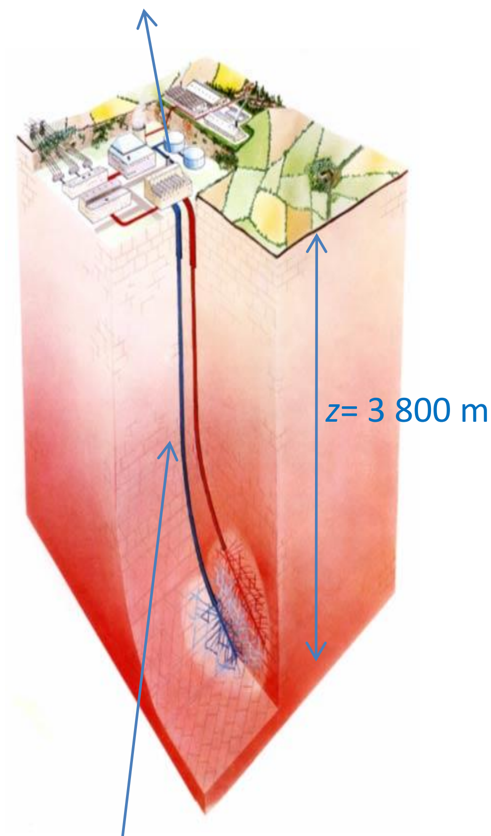
with β_1=4.226 $gCO_2eq/(m\cdot h)$ β_2=467.3 gCO_2eq/h; β_3=5.472gCO_2eq/kWh β_4=3261.2 gCO_2eq/h; β_5=381.2 kW



Affinity between the reference model and the 3-variables simplified model
R^2= 0,7
RMSE=8,17 gCO_2eq/kWh000

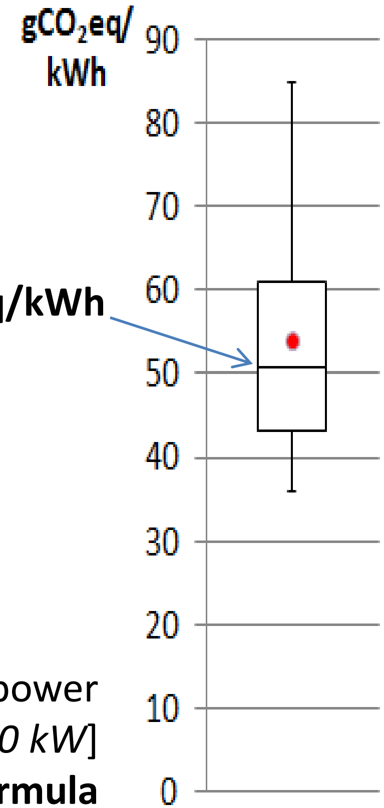
Elaboration and Discussion of Simplified Parameterized Models for Carbon Footprint of Enhanced Geothermal Systems M Lacirignola, BH Meany, I Blanc - World Geothermal Congress 2015, 2015

D3.4 : How to use the simplified model (EGS)



● : Result proposed by *Frick et al.(2010) [SiteA1]* through extensive LCA = **54 gCO_2eq/kWh**

$$GHG_{EGS} = \frac{Nw \cdot (\beta_1 \cdot z + \beta_2) + \beta_3 \cdot P_{ORC} + \beta_4}{P_{ORC} - \beta_5}$$ = **51 gCO_2eq/kWh**



Boxplot: GHG distribution profile for EGS power plants with [*2 wells, 3800 m depth, P_{ORC}= 1 240 kW*] calculated with the **Reference model formula**

Elaboration and Discussion of Simplified Parameterized Models for Carbon Footprint of Enhanced Geothermal Systems *M Lacirignola, BH Meany, I Blanc - World Geothermal Congress 2015, 2015*

SIMPLIFIED MODELS & DETAILED LCA MODELS

TASK		GEOENVI PARTNERS	OUTCOME
Advanced LCA course first week in April	M6	LCA experts and Programmers	Ability (1) to generate a simplified model for a case study (Wind turbines) & (2) to duplicate the method to generate the simplified model for GEOENVI Case studies
First version of the protocol to generate the simplified models	M9	ARMINES => the case studies partners	
Generation of the Explicit Reference LCA model	M8 ?	LCA experts for each case study	Explicit Reference detailed LCA model
Feedback on the protocol to generate the simplified models for geothermal installations	M11	The case studies partners => ARMINES	First version of the protocol
Generation of the simplified parameterized model for each case study	M18	LCA experts and Programmers	Simplified model ready to use for each GEOENVI case study (D3.4)