How to simplify Life Cycle Assessment in deep geothermal projects with the novel GEOENVI tool ?

The protocol to generate the simplified models

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Why simplified models and how to use them?

- 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 cases studies are currently under tested and first simplified models are reported today
- A simplified model for each impact category
- A range of operation and type of geothermal system per simplified model

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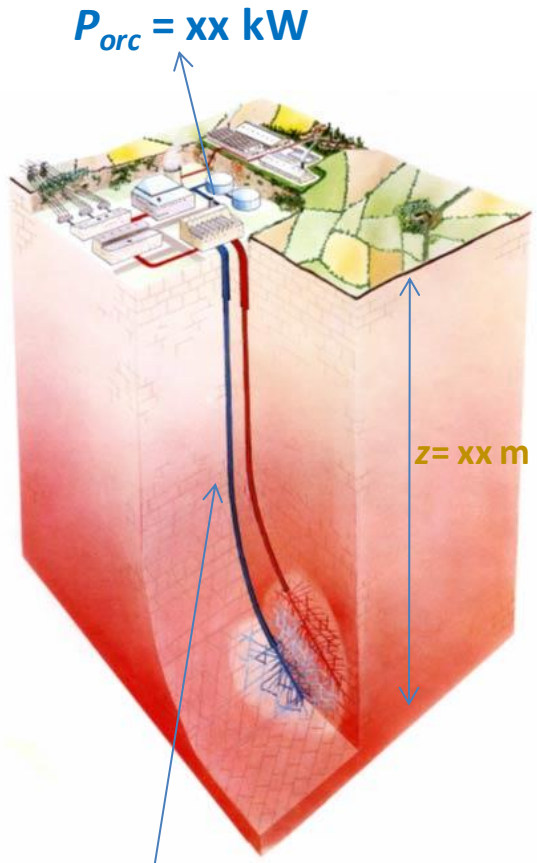
Example of a simplified model for EGS producing electricity



A simplified model based on 3 parameters:

P_{orc} , Z well depth, Nw nb of wells

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

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

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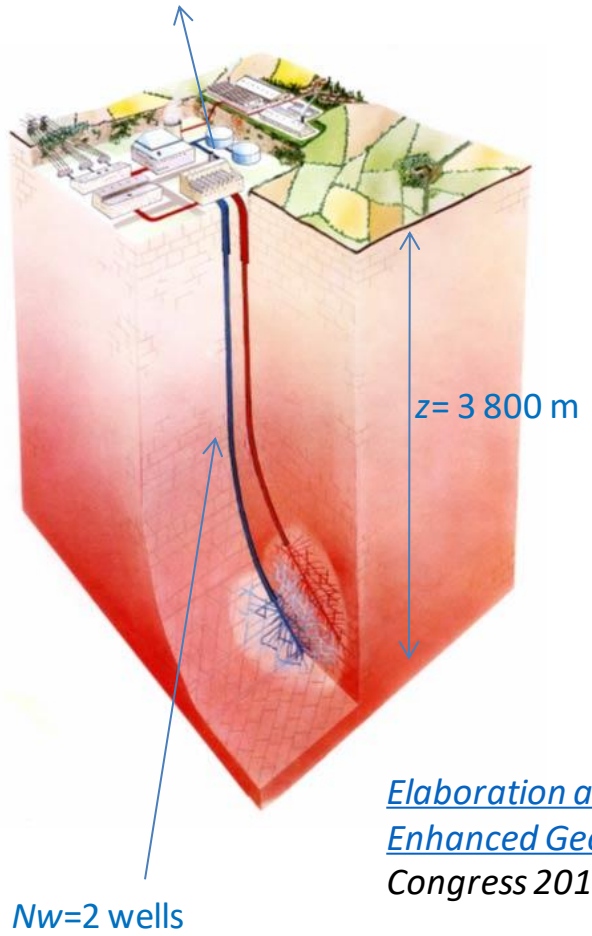
Use of the simplified model for EGS producing electricity



A simplified model based on 3 parameters:

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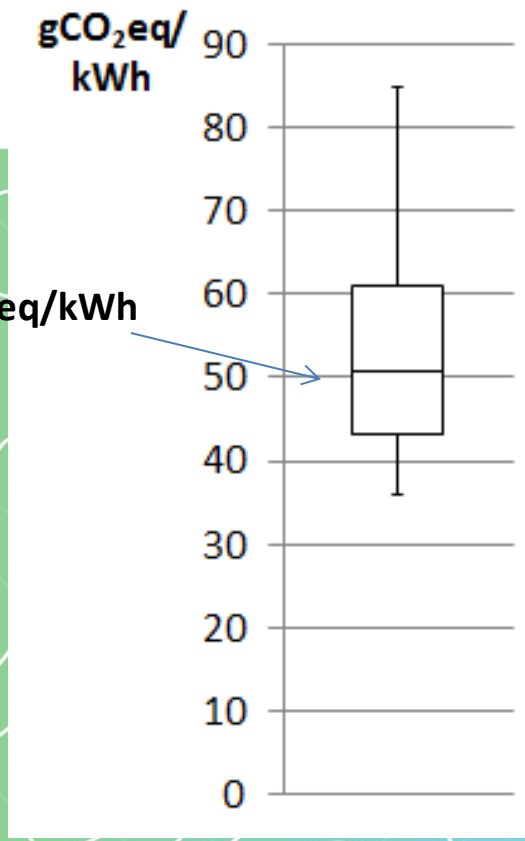
$$GHG_{EGS} = \frac{Nw \cdot (\beta_1 \cdot z + \beta_2) + \beta_3 \cdot P_{ORC} + \beta_4}{P_{ORC} - \beta_5}$$ = **51 gCO_2eq/kWh**



Case study for

[*2 wells, 3800 m depth and P_{ORC}= 1 240 kW*]

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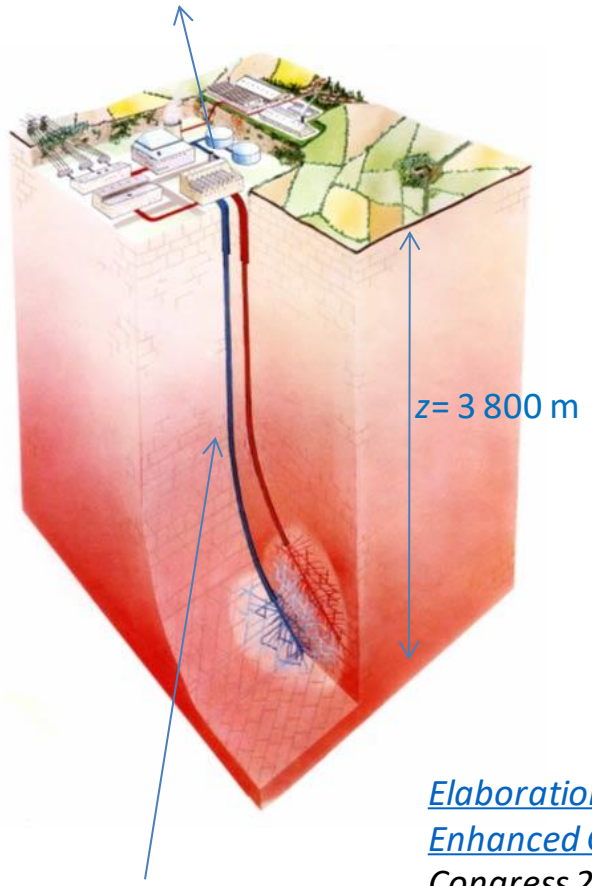
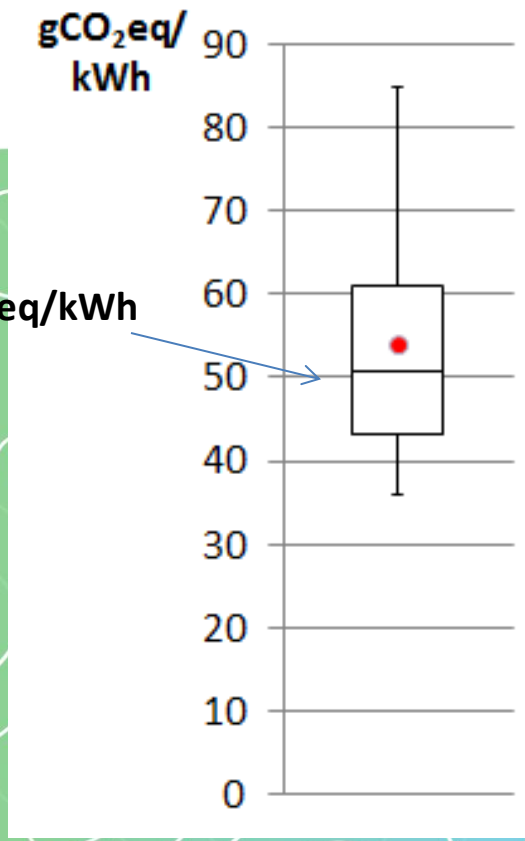
Validation of the simplified model with a reference study (Frick et al. 2010)



- *Detailed LCA Frick et al.(2010) [SiteA1]* = **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**



Case study with
[*2 wells, 3800 m depth and*
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The Protocol in 5 steps

1. **Scope of the study** : type of output / stimulation or not / type of conversion technology (dry steam, flash, binary)/ NCG abatement system or not, high level of direct emissions or not
2. **Definition of a reference parameterized LCA model** (choice of variables, their range and proxies) based on LCA guidelines and EU report (*)
3. Statistical process to identify the **key variables inducing the most variability** for each impact category (SOBOL INDEXES)
4. Generation of the **simplified model per impact category**
5. **Validation** of the simplified model with literature

(*)Geothermal plants and applications' emissions: overview and analysis

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• STEP1 : Scope of the study -- GEOENVI Case studies

	Rittershoffen (FR)	Bagnore (ITtaly)	Hellisheidi (Iceland)	Balmatt (Belgium)
Geothermal source type	Liquid	Vapour	Liquid/Vapour	Liquid
Energy generation technology	Direct heat use	Flash - hydrothermal	Single and double flash - hydrothermal	Direct heat use – ORC
Stimulation	Hydraulic- Thermal-Chemical			Chemical
Final energy use	Industrial heat	Electricity + Heat	Electricity + Heat	Heat (+ Electricity for self consumption)
Installed capacity	27 MWth	61 MWe 21.1 MWth	303.3 MWe 133 MWth	0.25 MWe 6.6 MWth

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The protocol to generate simplified models

(*)GSA = Global Sensitivity Analysis

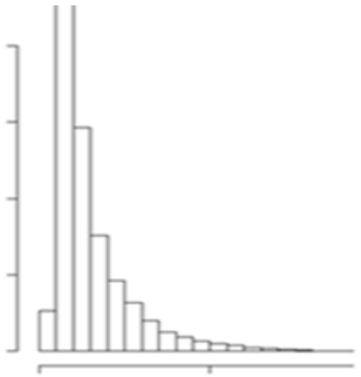
Step 1

Scope of the study

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

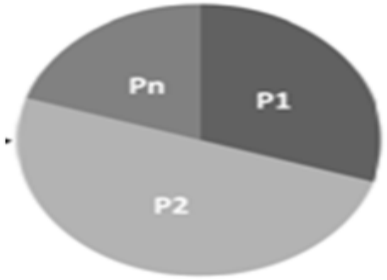
Step 2

Explicit Reference LCA model



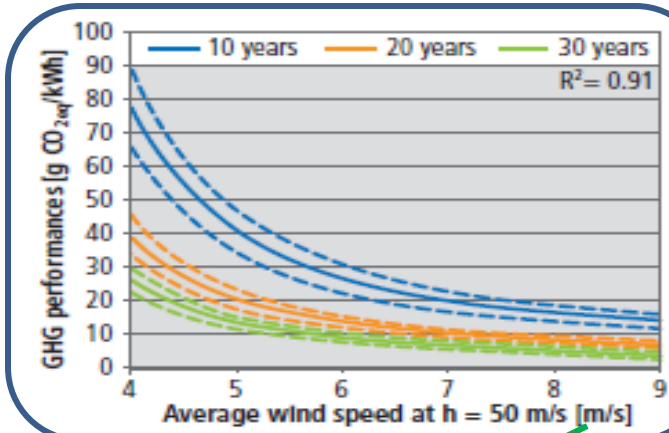
Step 3

Statistical Selection of key parameters by GSA(*)



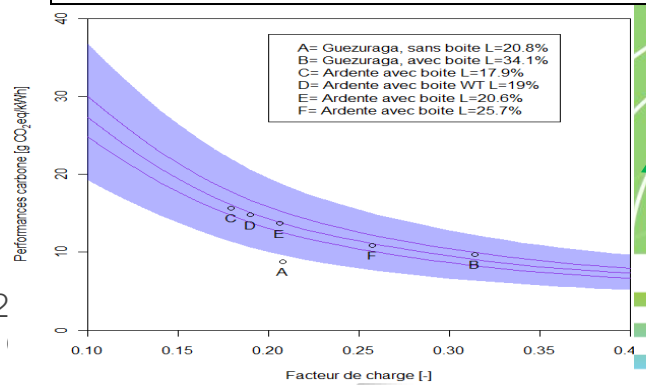
Step 4

Reduced parameterized model based on key variables



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**.

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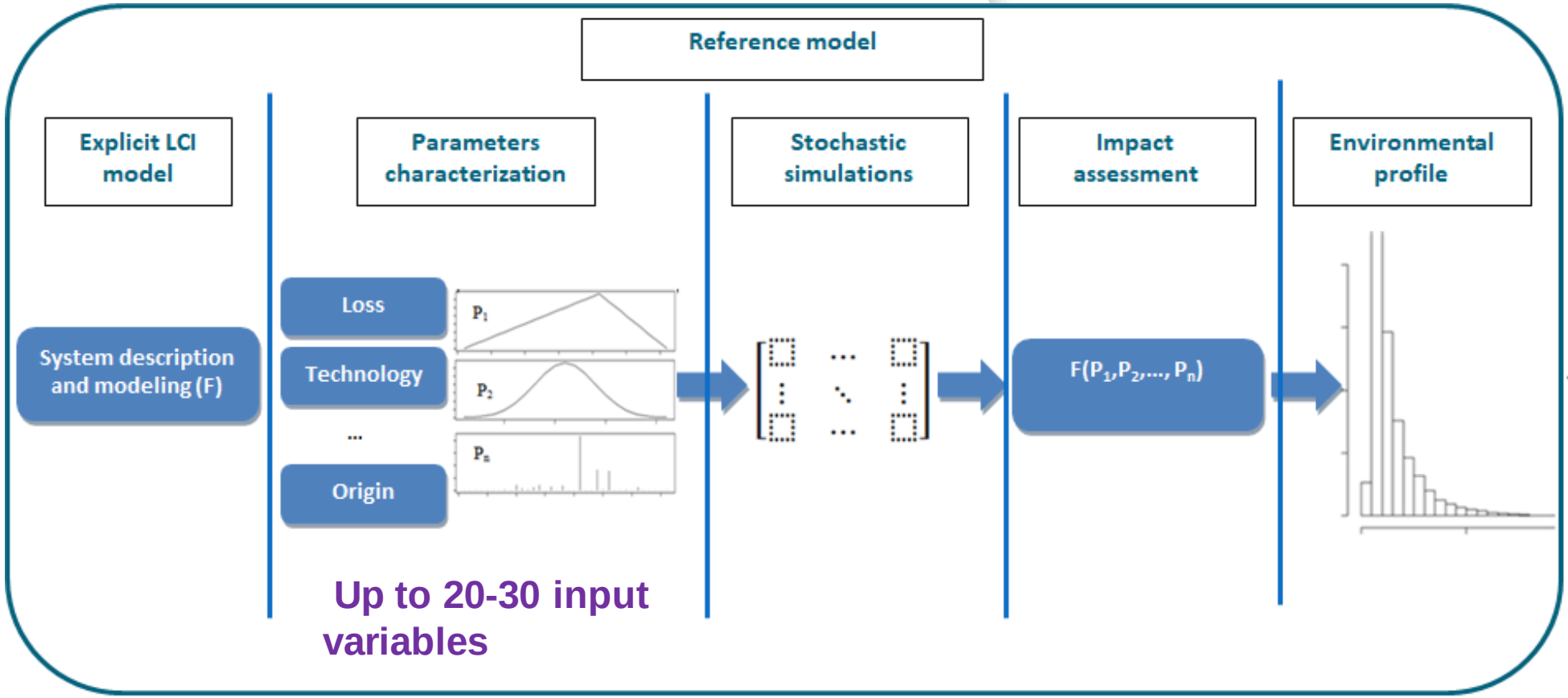
STEP2 : Reference parametrized LCA model



LCI : Life Cycle Inventory

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STEP2 : Reference parametrized LCA model

Rittershoffen heat generation plant example

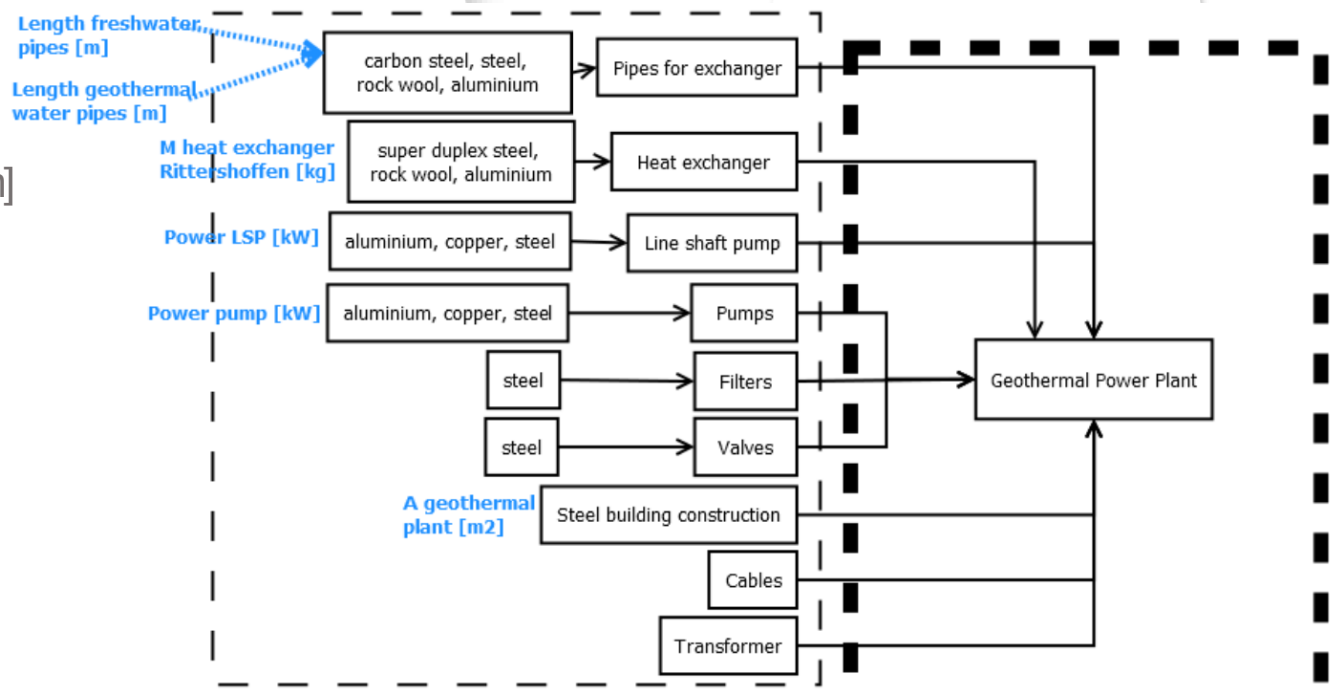
Construction – Geothermal power plant

Variables

- Lengths of fresh- and geothermal water pipes [m]
- Mass of heat exchanger in Rittershoffen [kg]
- Power line shaft pump [kW]
- Power pump [kW]
- Area of geothermal power plant [m^2]

Parameters

- Descriptions of retention basins (27.5x21m and 73x44.5m), mass of cables (1 9017kg), distance travelled for each equipment piece and pipes (500km), thickness aluminum in pipes (2mm), thickness rockwool in pipes (80mm)



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STEP 3 : Selection of key variables : how ?

- GSA application and Sobol indices calculation
  - Parameters variability fully integrated (interval and distribution)
  - Variability of all parameter assessed simultaneously
  - Parameters joint influences considered
  - Ranking of the parameter influence

GSA = Global Sensitivity Analysis

- Four sub-steps:
  - Stochastic generation of n scenarios
  - Computation of the impacts, applying the environmental reference performance model to the n generated scenarios
  - Estimation of the Sobol indices for each parameter,
  - Selection of the key parameters (q) explaining most of the variability

Click to add text

- Key parameters ➔ parameters which, when varied, are inducing the biggest variability on the environmental performance
  - Which parameters to be selected? Practitioner choice, cut-off criteria

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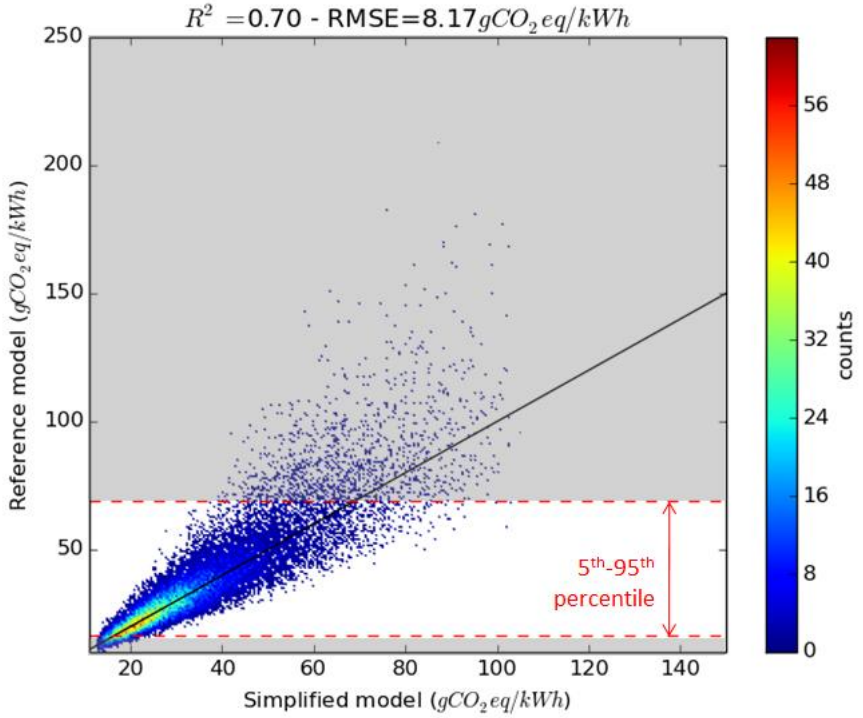
STEP 4 : Simplified model for climate change category

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



A 3 variables model explaining **75%** of the variability for GHG issued from the stochastic scenarios on the reference model

Affinity between the reference model and the 3-variables simplified model

R^2= 0,7

RMSE=8,17 $gCO_2eq/kWh000$

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Thank you

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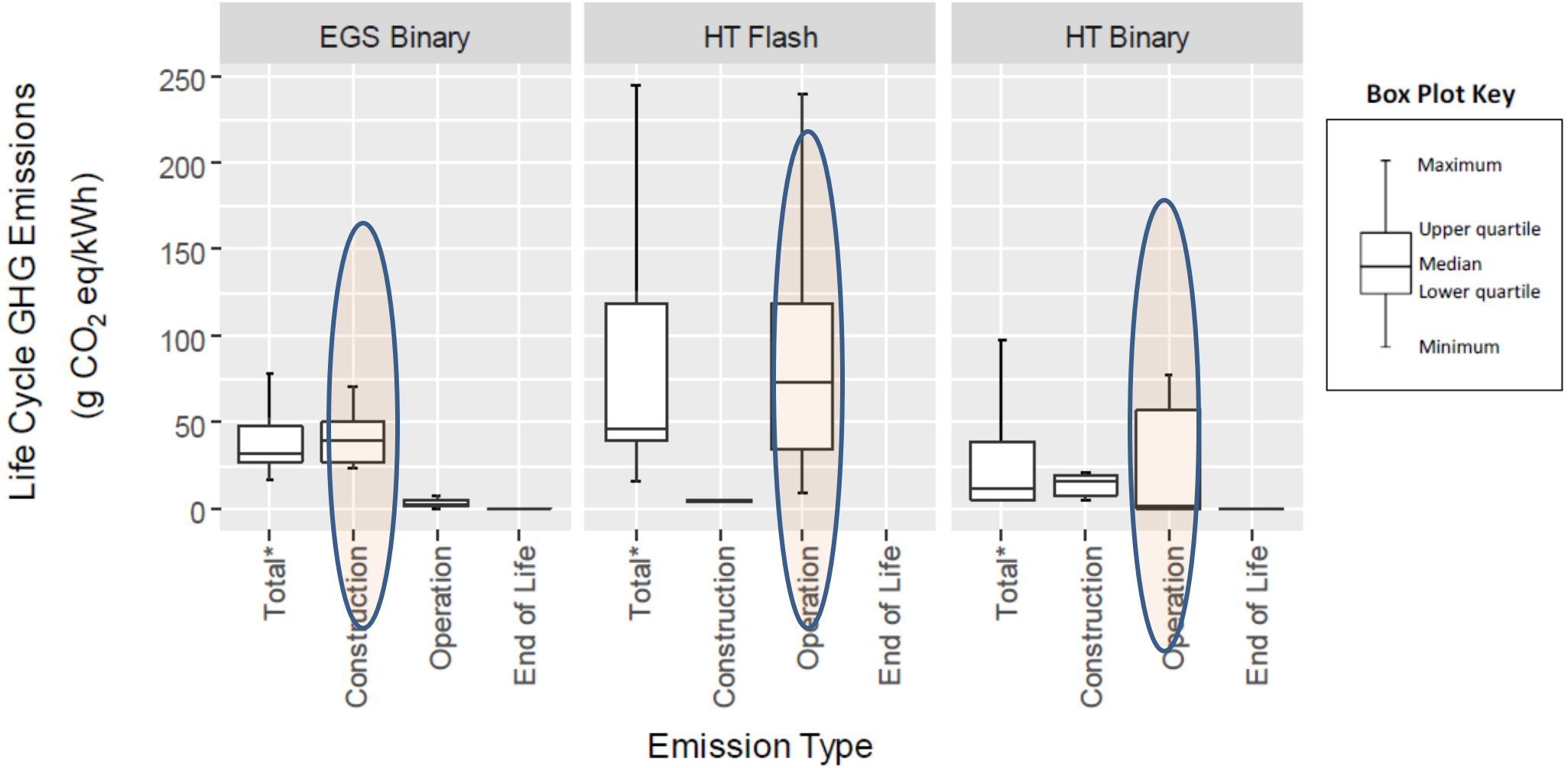

Sample Size: 18 8 8 4 9 7 8 0 8 6 6 4

Technical Report
NREL/TP-6A20-68474
September 2017

Systematic Review of Life Cycle Greenhouse Gas Emissions from Geothermal Electricity

Source :

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