Simplified models to assess environmental impacts for geothermal installations

(3) A simplified model for a geothermal system
Liquid/Vapour- hydrothermal system

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CIRCULAR

ORKUSTOFNUN
National Energy Authority

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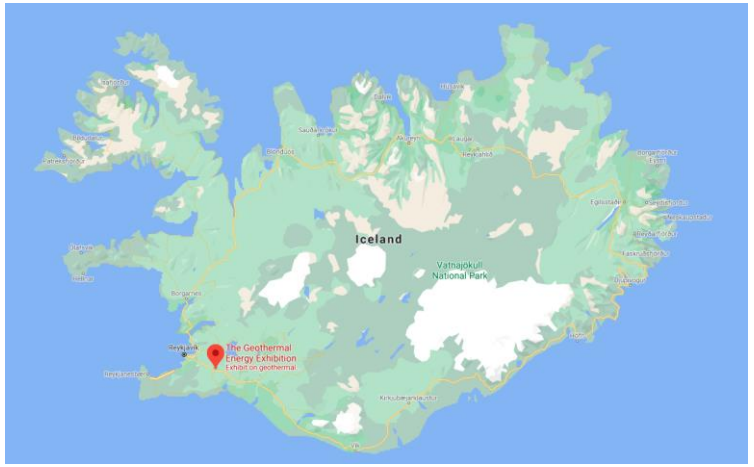
GEOENVI

2 / Representative Geothermal System (RGS) = Hellisheiði



PROJET CONTEXT

- Located 18 km outside of Reykjavik
- Plant occupies 112 km2
- Single and Double flash power plant
- Combined Heat and Power Plant with:
  - 303 MW Electrical Capacity
  - 133 MW Thermal Capacity

- Novel CarbFix method integrated, mitigating CO2 and H2S through geological storage.

Image source: Orka Náttúrannar

Reykjavík Energy

ORKA NÁTTÚRUNNAR

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PLANT DESCRIPTION

Construction

- Well Drilling
  - 47 Geothermal drilled + 17 reinjection wells
  - Average well depth ~2,220 m, with ±800-900m variation
  - Average diesel use per meter of well drilled ~57-65 L/m
- Collection pipelines
  - 36,000m of pipeline for construction phase
  - Average of ~765m per well
  - 197 kg of steel needed per meter pipe

Image source: Orka Náttúrannar

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PLANT DESCRIPTION

Maintenance

- Make up wells
  - 23 make up wells estimated, ±7 wells variability
  - 9,000m additional collection pipelines
- Make up wells include electric drilling
  - Electric drilling LCI included using data from drill rig operators
  - Estimated % of make up wells electrically drilled dependent on number of makeup wells needed within case study
- Machinery maintenance included
  - Estimated to be 1% of production materials with ±0.5% variability

Operations

- Emissions from power plants
  - 1.4 g CO2/kg-geothermal fluid with Min and Max 1.152 and 2.304, respectively
  - 0.0021 g CO2/kg-geothermal fluid with Min and Max 0.0014 and 0.0024, respectively
  - CO2 and H2S emissions experience long-term variability due to fluctuations of reservoir composition
- Operations
  - Average electrical capacity factor 87% with Min and Max 79% and 94% over five year period, respectively
  - Average thermal capacity factor 55% with Min and Max 42% and 67% over five year period, respectively
  - 30 year estimated lifetime

Abatement

- Abatement provided by CarbFix method included, with the following characteristics:
  - Ability to sequester~34% CO2 and 71% H2S emissions
  - 585 kW electrical capacity required
  - 88.5% estimated capacity factor with ~ ±12% variability

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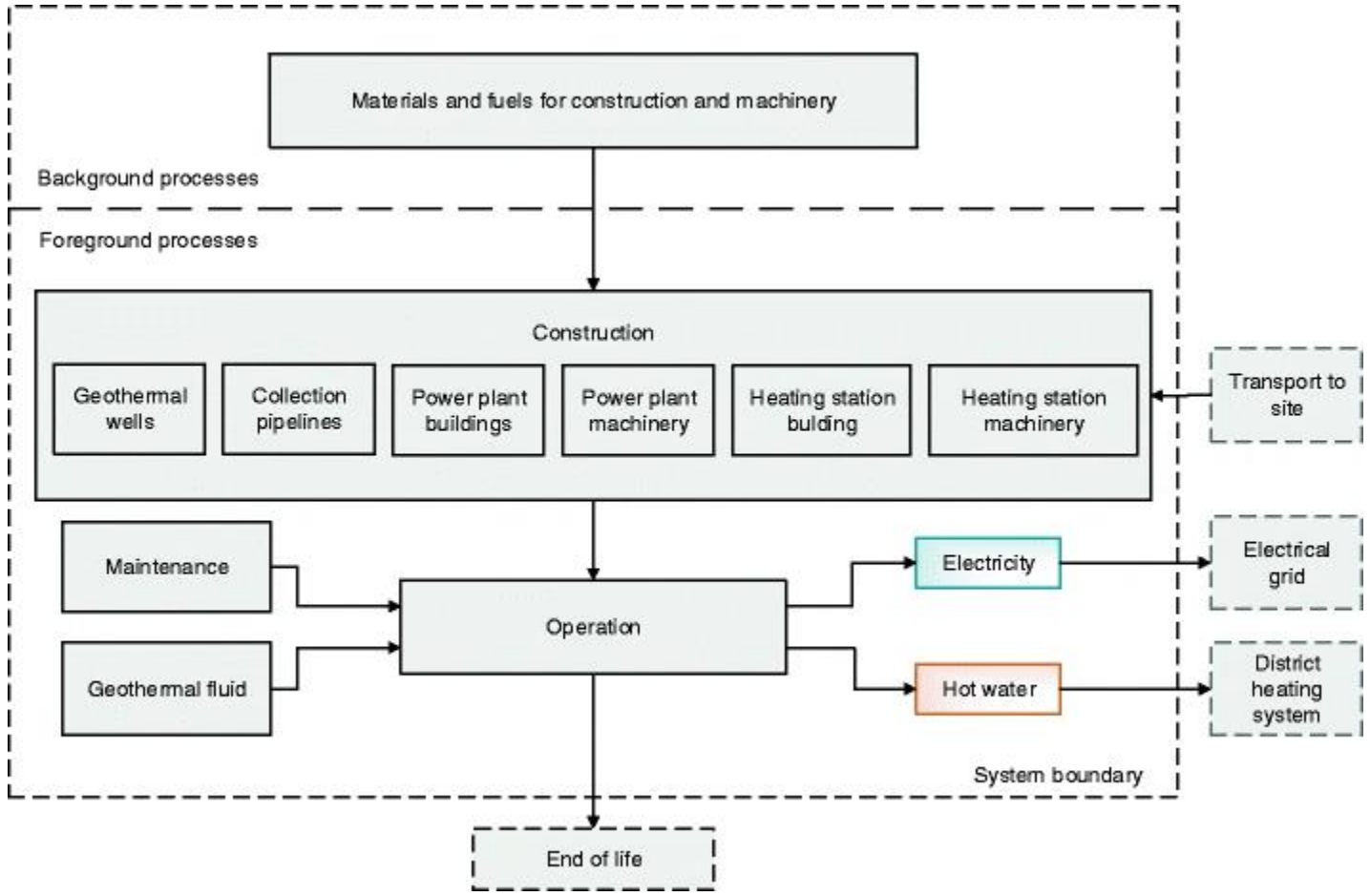
Definition of the reference parametrized LCA model



- Simplified scheme of the LCA reference parameterized model
- Main variables used for parametrization highlighted in blue

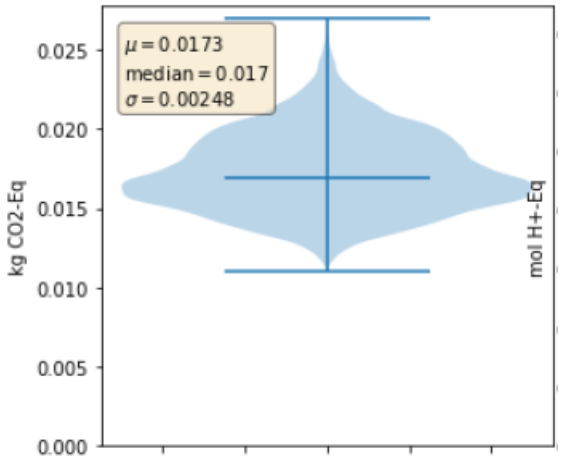
Karlsdóttir, Marta Rós, et al. "Life cycle inventory of a flash geothermal combined heat and power plant located in Iceland." The International Journal of Life Cycle Assessment 20.4 (2015): 503-519.

Definition of the variables for the reference parametrized LCA model

Variable parameter	Description of factors	Unit	default	min	max
Number_of_production_wells	Number of production wells required (wide and narrow)	number of	47	28.2	65.8
Number_of_injection_wells	Number of injection wells required	number of	17	10.2	23.8
Number_of_makeup_wells	Number of make-up wells required	number of	23	16	30
Well_depth	Depth of each well	meter	2,242	1,394	3,323
Steel_in_casing	Steel amount in casing	kg/m well depth	90.4	81	118
Diesel_use_during_drilling	Diesel use during drilling	MJ/m well depth	2,270.1	1,022	3,632
Length_of_pipelines	Length of collection pipelines from boreholes to power plant	meter	36,000	21,600	50,400
Steel_in_pipelines	Steel use in pipelines	kg/meter	197	118.2	275.8
Steel_in_building	Steel use in buildings	kg/MW	35,115	21,069	49,161
Steel_in_machinery	Steel use in machinery	kg/MW	9,850	5,910	13,790
CO2_in_geofluid	CO2 in geofluid	g/kg geofluid	0.0014	0.0012	0.0023
Capacity_factor	Power generation capacity factor	-	0.87	0.6	1
Power_output	Electrical output	MW	303	400	500
Lifetime	Lifetime of the power plant	Years	30	20	40

Image source: Orka Náttúrannar

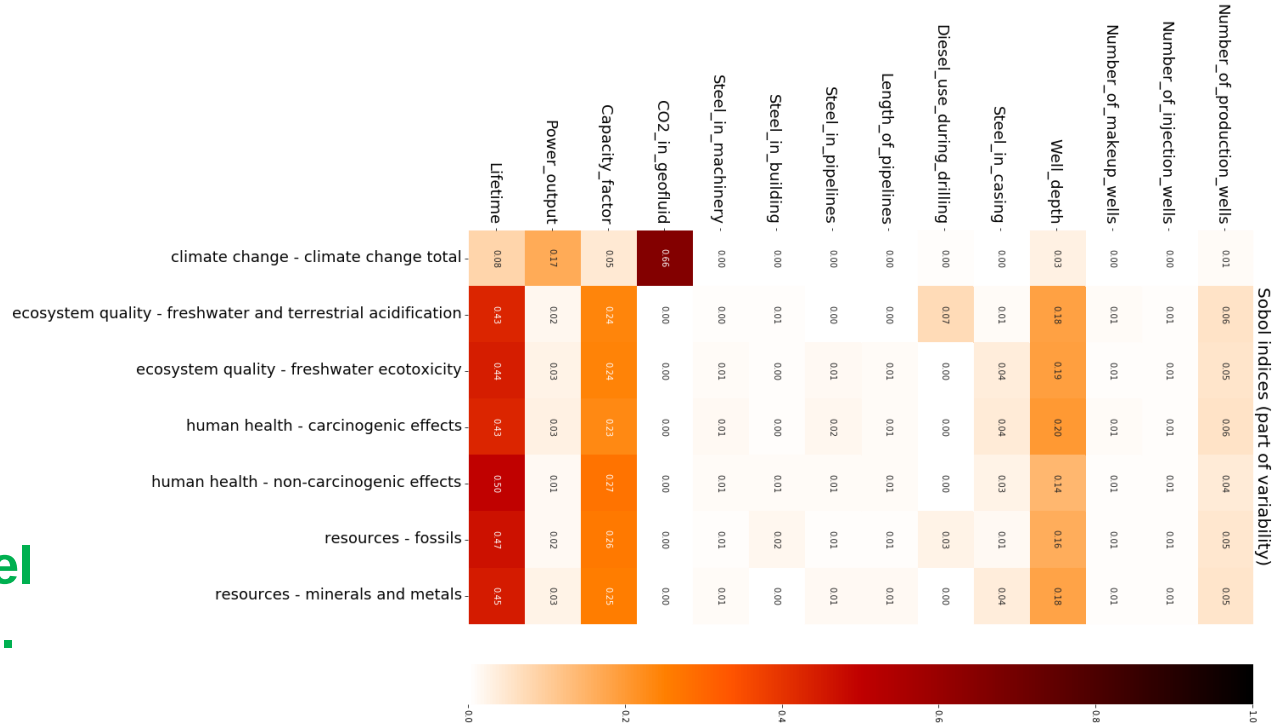
Selection of key variables after running the Global Sensitivity Analysis (Sobol indexes)



Key parameters

1. CO2 concentration in geofluid,
2. Power output,
3. Lifetime
4. Capacity factor
5. Well depth
6. Diesel use during drilling

→ Per indicator, the simplified model uses 2 to 6 of these key parameters.



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Simplified model for climate change category

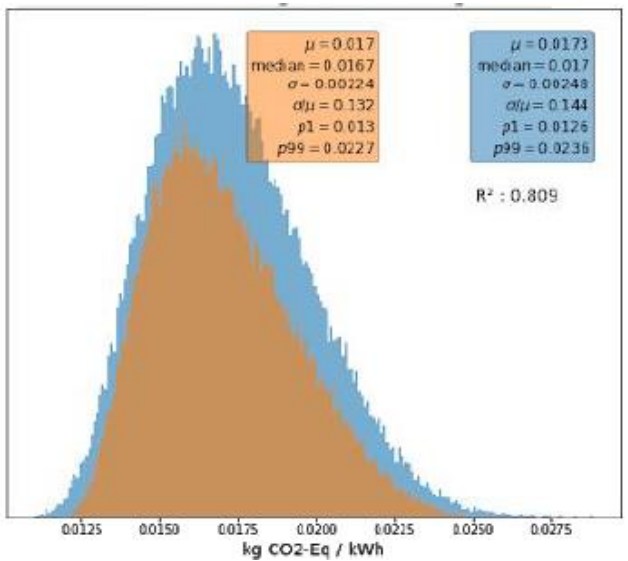
From *f(14 variables)* => *ϕ(2 variables)* :

Simplified model formula (2-variables):

$$\frac{3.63 \cdot 10^{3} CO_{2 ingeo fluid}}{Power_{output}} + 1.4 \cdot 10^{-6} Power_{output} + 0.000625 + \frac{1.02}{Power_{output}} + \frac{77.1}{Power^{2}_{output}}$$

Simplified model

Reference LCA model



A 2 variables model explaining **83 %** of the variability for GHG issued from the stochastic scenarios on the reference model

Affinity between the reference model and the 2-variables simplified model

R^2= 0.809

(overlap between estimates of the reference and the simplified model)

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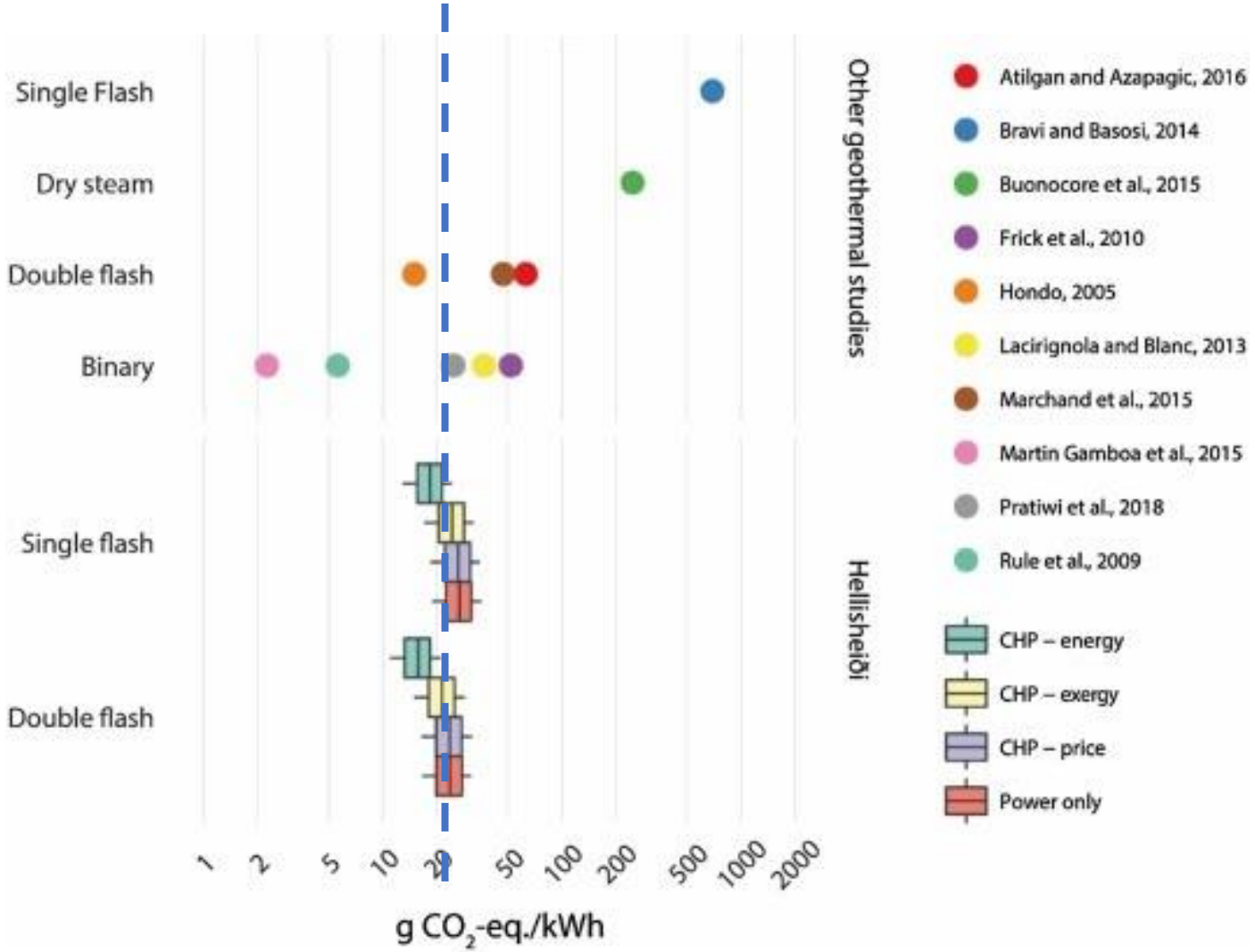
Domain of validity for both models : the Reference LCA model and the simplified models

- A system with a hydrothermal liquid/vapor geothermal source, natural flow
- Single or double flash system producing both heat and electricity.
- There is no abatement technology connected and
- the electrical output is in the range of 200 to 400 MWe MWe (high capacity factor)
- Thermal output is 133 MWth about 50% capacity factor.
- The range of values for the variable parameters as specified in Table 9 (Douziech et al., 2020)

Douziech, M., Blanc, I., Damen, L., Dillman, K., Eggertsson, V., Ferrara, N., Gudjonsdottir, S.R., Harcouët-Menou, V., Parisi, M.L., Pérez-López, P., Ravier, G., Sigurjonsson, H., Tosti, L., 2020. Generation of simplified parametrised models for a selection of GEOENVI geothermal installation categories. D3-4. GEOENVI Project # 818242.

Domain of validity for both models : the Reference LCA model and the simplified models



This results in 21.6 g CO2/kWh for the climate change impact category which is well in line with the results from the paper, reporting between 18 and 24 g CO2-eq./kWh for single flash configuration and between 15 and 23 g CO2-eq./kWh for double flash configuration.