GEOPHIRES v3 User Manual

National Renewable Energy Laboratory (NREL)

List of Acronyms

CAPEX	capital expenditures
CHP	combined heat and power
CLGS	closed-loop geothermal system
EGS	enhanced geothermal system
IBI	investment-based incentive
NPV	net present value
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OPEX	operational expenditures
ORC	organic Rankine cycle
PPA	power purchase agreement
SAM	System Advisor Model
SBT	slender body theory

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Introduction

This manual is designed to guide users in running geothermal techno-economic simulations using the GEOPHIRES software tool. It includes a brief overview of GEOPHIRES, a quick-start guide, and descriptions of the built-in example problems. The manual also provides instructions for extending the tool, conducting Monte Carlo simulations, and integrating GEOPHIRES with the National Renewable Energy Laboratory's (NREL's) System Advisor Model™ (SAM). Additionally, it details the required input file format and includes a comprehensive list of all input parameters, along with their descriptions, units, allowable values, and default settings.

The latest version of GEOPHIRES v3, this manual, and example simulations are available on the GEOPHIRES GitHub repository: github.com/NREL/GEOPHIRES-X. This repository is the canonical source for the modern GEOPHIRES simulator, which succeeds the legacy GEOPHIRES v2.0. The name GEOPHIRES-X refers to the initial modernized (v3) framework. See the CHANGELOG for a detailed history of changes and release notes.

The GEOPHIRES web interface can be accessed at: gtp.scientificwebservices.com/geophires/.

1 GEOPHIRES Overview

GEOPHIRES combines reservoir, wellbore, surface plant, economic and cost models, and correlations to estimate the capital expenditures (CAPEX) and operations and maintenance (O&M) costs, instantaneous and lifetime energy production, and overall levelized cost of energy of a geothermal plant.

The high-level software architecture is illustrated in Figure 1. The green, orange and blue rectangles refer to internal GEOPHIRES components, external user interface components, and external reservoir simulators (TOUGH2), respectively. The rectangles with a solid outline are always executed during a simulation run; the rectangles with a dashed outline refer to optional or user-provided components.

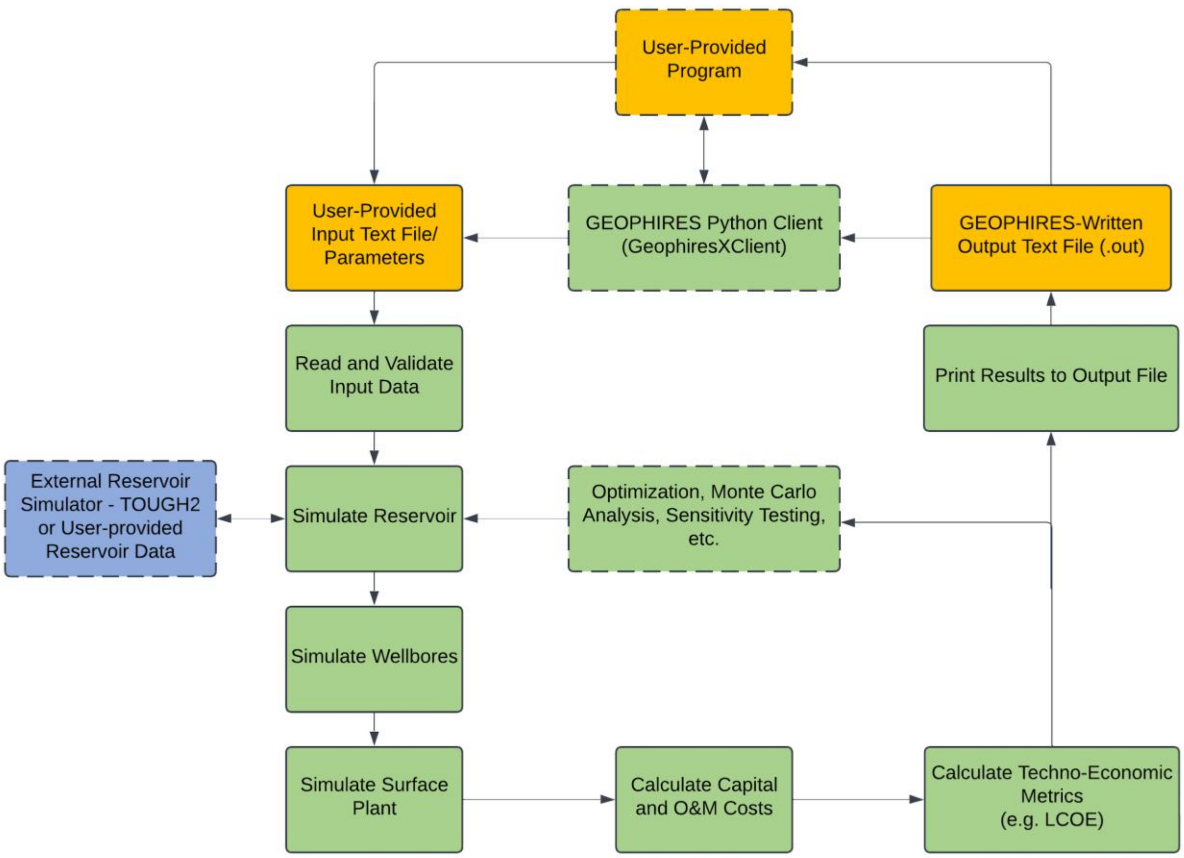

Figure 1. GEOPHIRES software architecture

GEOPHIRES has a variety of different reservoir models, including (1) the multiple parallel fractures model (Gringarten); (2) a one-dimensional linear heat sweep model; (3) an M/A thermal drawdown parameter model; (4) a percentage temperature drawdown model; (5) user-provided reservoir temperature production data; (6) coupling to the TOUGH2 external reservoir simulator; (7) SUTRA; (8) slender body theory (SBT); and (9) cylindrical reservoir.

GEOPHIRES can simulate three different end uses of the geothermal heat: (1) direct-use heat (e.g., for industrial processing heating or residential space heating), (2) electricity (with subcritical organic Rankine cycle [ORC], supercritical ORC, a single-flash plant, or a double-flash plant), and (3) cogeneration of heat and electricity. The cogeneration option considers the bottoming cycle, the topping cycle, and the parallel cycle.

GEOPHIRES has four economic models to calculate the levelized cost of heat or electricity: (1) the fixed charge rate model, (2) the standard discounting levelized cost model, (3) the BICYCLE model, and (4) the closed-loop geothermal system (CLGS) model.

The capital and O&M costs for the different geothermal system components (e.g., exploration, well drilling, surface plant) are either provided by the user or calculated with built-in correlations.

For more information on the theoretical basis for GEOPHIRES, see (Beckers and McCabe 2019a) GEOPHIRES v2.0: updated geothermal techno-economic simulation tool.

2 Quick-Start Guide

A web interface is available at gtp.scientificwebservices.com/geophires.

2.1 Installation

If Python is not already installed, download it from www.python.org along with the necessary libraries (math, datetime, numpy, time, os, sys). To check whether Python is already installed, type "python" in a command window. If it is installed, the version will be displayed.

If the user does not need to view or edit the GEOPHIRES source code, it can be installed as a regular (non-editable) Python package using the following command:

```
pip3 install https://github.com/NREL/GEOPHIRES-X/archive/main.zip
```

However, an editable installation is recommended for most users. This allows the user to run GEOPHIRES locally, view its Python files in an integrated development environment or text editor, and create their own extensions.

Prerequisites:

- Python 3.8 or later:
    - Download from python.org/downloads.
    - (On Ubuntu: run alias python=python3 if it is not already aliased.)
- Git
- Virtual environment tool (venv) (Install if it is not already available.)
- Windows users (Administrative privileges might be required to activate the virtual environment.)

Installation steps (editable version):

- Open a command line terminal (e.g., Terminal on macOS, PowerShell on Windows).
- Create a project directory for GEOPHIRES:

```
mkdir my-geophires-project
   cd my-geophires-project
```

- Create a virtual environment:

```
python -m venv venv
```

- Activate the virtual environment:

  Windows: `venv\Scripts\activate`

  macOS/Linux: `source venv/bin/activate`

- Install the editable version of GEOPHIRES:

```
pip3 install -e git+https://github.com/NREL/GEOPHIRES-X.git#egg=geophires-x --src .
```

- Run an example file:

```
cd geophires-x
cd tests
cd examples
python -mgeophires_x example1.txt
```

- To view or edit the source code, open the my-geophires-project/ directory in an integrated development environment, such as PyCharm, Spyder, or Visual Studio Code. The GEOPHIRES source code is located in:

  ```
  my-geophires-project/geophires-x
  ```

- The user can add their own Python files in `my-geophires-project/` that use the source code as a module.
- To update GEOPHIRES to the latest version:
  - Navigate to the source folder and pull the latest changes from GitHub:

    ```
    cd geophires-x
    git pull
    ```

  - Resolve merge conflicts if any appear.

    ```
    pip install -e .
    ```

- Download TOUGH2 (optional): If the user would like to use the coupling with TOUGH2 (reservoir option 6), a TOUGH2 executable should be provided in the GEOPHIRES folder. Downloading and running a TOUGH reservoir simulator requires purchasing a license from Lawrence Berkeley National Laboratory.

2.2 Usage

2.2.1 Example Usage in Python

```
from geophires_x_client import GeophiresXClient
from geophires_x_client.geophires_input_parameters import
GeophiresInputParameters

client = GeophiresXClient()
result = client.get_geophires_result(
            GeophiresInputParameters({
                "Gradient 1": "69",
                "Reservoir Depth": "5",
                "End-Use Option": "1",
                "Power Plant Type": "4"
            })
        )

with open(result.output_file_path, 'r') as f:
    print(f.read())
```

For this editable installation example, put this code in `my-geophires-project/main.py`, then run:

```
python main.py
```

The displayed output will include a case report:

```
(venv) ➜  my-geophires-project python main.py
No valid plant outlet pressure provided. GEOPHIRES will assume default plant
outlet pressure (100 kPa)
No valid plant outlet pressure provided. GEOPHIRES will assume default plant
outlet pressure (100 kPa)

                               *****************
                               ***CASE REPORT***
                               *****************

Simulation Metadata
----------------------
 GEOPHIRES Version: 3.4.42
 Simulation Date: 2024-07-08
 Simulation Time:  10:07
 Calculation Time:      0.047 sec

                           ***SUMMARY OF RESULTS***

      End-Use Option: Electricity
      Average Net Electricity Production:                    23.94 MW
      Electricity breakeven price:                            5.04 cents/kWh

[...]
```

Parameters can also be passed as a text file:

```
from pathlib import Path
from geophires_x_client import GeophiresXClient
from geophires_x_client.geophires_input_parameters import
GeophiresInputParameters

# https://github.com/NREL/GEOPHIRES-X/blob/main/tests/examples/example1.txt
example_file_path = Path('geophires-
x/tests/examples/example1.txt').absolute()

client = GeophiresXClient()
result = client.get_geophires_result(
            GeophiresInputParameters(from_file_path=example_file_path)
        )

with open(result.output_file_path, 'r') as f:
    print(f.read())
```

Additional examples of how to consume and call GEOPHIRES XClient (https://github.com/NREL/GEOPHIRES-X/blob/main/src/geophires_x_client/__init__.py#L14) can be found in test_geophires_x.py.

2.2.2 Command Line

If installed with pip (editable or non-), GEOPHIRES can be run from the command line, passing the input file as an argument:

```
python -mgeophires_x my_geophires_input.txt
```

The user can also optionally pass the output file as well:

```
python -mgeophires_x my_geophires_input.txt my_geophires_result.out
```

(If an output file argument is not passed, a default name will be used.)

3 Example Problems

A variety of example problems (see Table 1) are included in the GEOPHIRES GitHub folder and the web interface considering different reservoir types, reservoir models, end uses, and economic models. Starting with an existing GEOPHIRES example that is similar to the user's intended use or application can be an easier approach to using GEOPHIRES than constructing inputs from scratch.

Table 1. Overview of Example Problems Included in the GEOPHIRES GitHub Folder

Example Problem	Reservoir Type/Configuration	Reservoir Model	End Use	Economic Model
Example 1	Enhanced geothermal system (EGS)	Multiple parallel fractures	Electricity with supercritical ORC	Fixed charge rate
Example 2	EGS	1D linear heat sweep	Industrial direct-use heat	Standard levelized cost of energy
Example 3	EGS	M/A single-fracture drawdown	Combined heat and power (CHP): double-flash topping industrial direct-use heat; electricity as main product	BICYCLE
Example 4	Hydrothermal	Percentage thermal drawdown	Electricity with subcritical ORC	BICYCLE
Example 5	EGS	User-provided reservoir output temperature data	Industrial direct-use heat	BICYCLE
Example 6	Hydrothermal	TOUGH2 doublet—multiple gradients	Industrial direct-use heat	Standard levelized cost
Example 7	Hydrothermal	TOUGH2 doublet—single gradient	Industrial direct-use heat	Standard levelized cost
Example 8	EGS	Multiple parallel fractures—Cornell	Industrial direct-use heat	Fixed charge rate
Example 9	EGS	Multiple parallel fractures—Cornell	Electricity with subcritical ORC	Fixed charge rate
Example 10	EGS	M/A single-fracture drawdown	Direct-use with heat pump	BICYCLE
Example 11	EGS	M/A single-fracture drawdown	Direct-use with absorption chiller	BICYCLE
Example 12	EGS	Multiple parallel fractures	Direct-use with district heating	Standard levelized cost
Example 13	Hydrothermal	Percentage thermal drawdown	Cogen bottoming cycle, heat as main product	Standard levelized cost

Example Problem	Reservoir Type/Configuration	Reservoir Model	End Use	Economic Model
CLGS: coaxial sCO_2 heat	Coaxial	N/A	Industrial direct-use heat	CLGS
CLGS: coaxial water heat	Coaxial	N/A	Industrial direct-use heat	CLGS
CLGS: u-loop sCO_2 electricity	U-loop	N/A	Electricity	CLGS
CLGS: u-loop sCO_2 heat	U-loop	N/A	Industrial direct-use heat	CLGS
CLGS: u-loop water electricity	U-loop	N/A	Electricity	CLGS
CLGS: u-loop water heat	U-loop	N/A	Industrial direct-use heat	CLGS
CLGS: SBT high temperature	EavorLoop	SBT	Electricity with supercritical ORC	BICYCLE
CLGS: SBT low temperature	EavorLoop	SBT	Electricity with supercritical ORC	BICYCLE
SUTRA example 1	Reservoir thermal energy storage	SUTRA	Industrial direct-use heat	Standard levelized cost
Multiple gradients	EGS	Multiple parallel fractures	Electricity with supercritical ORC	Fixed charge rate
Investment tax credit	EGS	Multiple parallel fractures	Electricity with supercritical ORC	BICYCLE
Production tax credit	EGS	Multiple parallel fractures	Electricity with supercritical ORC	BICYCLE
Fervo project red (2023)	EGS	Multiple parallel fractures	Electricity with supercritical ORC	BICYCLE
Fervo Cape Station 1: 2023 results	EGS	Multiple parallel fractures	Electricity with supercritical ORC	BICYCLE
Fervo Cape Station 2: 2024 results	EGS	Multiple parallel fractures	Electricity with supercritical ORC	BICYCLE
Fervo Cape Station 3: 400-MWe production	EGS	Multiple parallel fractures	Electricity with supercritical ORC	BICYCLE
500-MWe EGS project modeled on	EGS	Multiple parallel fractures	Electricity with supercritical ORC	SAM single-owner power purchase agreement (PPA)

Example Problem	Reservoir Type/Configuration	Reservoir Model	End Use	Economic Model
Fervo Cape Station				
Superhot rock example 1	EGS	Multiple parallel fractures	Electricity, single flash	Fixed charge rate
Superhot rock example 2	EGS	Multiple parallel fractures	Electricity, single flash	Fixed charge rate
SAM single-owner PPA: 50 MWe	EGS	Multiple parallel fractures	Electricity with supercritical ORC	SAM single-owner PPA
SAM single-owner PPA: 400-MWe BICYCLE comparison	EGS	Multiple parallel fractures	Electricity with supercritical ORC	SAM single-owner PPA
SAM single-owner PPA: 50-MWe with add-on	EGS	Multiple parallel fractures	Electricity with supercritical ORC	SAM single-owner PPA

3.1 Case Study: 500-MWe EGS Project Modeled on Fervo Cape Station

The GEOPHIRES example Fervo_Project_Cape-4 (nrel.github.io/GEOPHIRES-X/Fervo_Project_Cape-4.html) is a case study of a 500-MWe EGS project modeled on Fervo Energy's Cape Station with its recently announced (April 2025) upsizing from 400 MW to 500 MW. Case study inputs are formulated using a combination of publicly available data, extrapolations, and estimates. Financial results are calculated using the SAM single-owner PPA economic model.

The case study is constructed to be representative of a 500-MWe EGS project similar to Cape Station, but it is not intended to be an exact facsimile. This is because not all relevant data points are publicly available (e.g., full PPA terms), and others might not be applicable outside of Cape Station's first-of-a-kind status (such as the drilling costs of the initial wells, which were more expensive, at \$4.8–9.4 million per well).

Exact values were used for publicly available technical and engineering parameters, such as reservoir density (2,800 kg/m³). Some technical parameters were inferred with high confidence from publicly available data, such as geothermal gradient (74°C/km) and well diameter. Other parameters were extrapolated or speculatively estimated based on plausibility and/or compatibility with known results, such as the number of doublets.

The following inputs and results tables (tables 2–5) document key assumptions, inputs, and a comparison of results with reference values. Note that these are not the complete sets of inputs and results, which are available in the source code and the web interface.

Given the methodological approach, including the speculative estimations of some input parameters, and the lack of real-world reference data for comparison, the case study results are subject to uncertainty. This case study does not attempt to quantify uncertainties, but sensitivity analysis might be included in future updates. Users might wish to perform their own sensitivity analysis using GEOPHIRES's Monte Carlo simulation module (https://nrel.github.io/GEOPHIRES-X/Monte-Carlo-User-Guide.html) or other data analysis tools.

3.1.1 Economics Parameters

Table 2. Economics Parameters

Parameter	Input Value(s)	Source
Economic model	SAM single-owner PPA	The SAM single-owner PPA economic model is used to calculate financial results, including the levelized cost of energy, net present value (NPV), internal rate of return, and pro-forma cash flow analysis. See GEOPHIRES documentation of SAM economic models (https://softwareengineerprogrammer.github.io/GEOPHIRES/SAM-Economic-Models.html) for details on how SAM financial models are integrated into GEOPHIRES.
Inflation rate	2.3%	U.S. inflation rate as of April 2025
PPA price	Starting at 9.5 cents/kWh, escalating to 10 cents/kWh by project year 11	Upper end of ranges given in the 2024 NREL Annual Technology Baseline (NREL 2024). Both PPAs' "firm for 10 years at less than $100/MWh" estimates are given in a podcast.
Well-drilling cost correlation and adjustment factor	Vertical large baseline correlation + adjustment factor = 0.8 to align with Fervo claimed-drilling costs of <$4 million/well	Akindipe and Witter (2025); Latimer (2025)
Reservoir stimulation capital cost per well	$4.6 million (all-in cost, including 15% contingency)	The all-in cost is based on an approximate $4.0 million baseline stimulation cost, calibrated from the per-stage costs of high-intensity U.S. shale wells (Baytex Energy 2024; Quantum Proppant Technologies 2020), which are the closest technological analogue for multistage EGS (Gradl 2018). This baseline assumes standard sand proppant. The 15% contingency (approximately $0.6 million) accounts for the necessary upgrade to ceramic proppant, which is required to resist mechanical crushing and geochemical degradation (diagenesis) over a 30-year well life at 200°C (Ko, Ghassemi, and Uddenberg 2023; Shiozawa and McClure 2014).
Capital cost for power plant for electricity generation	$1,900/kW	DOE (2021)
Discount rate	12%	Typical discount rates for high-risk projects can be 12%–15%.

Parameter	Input Value(s)	Source
Inflated bond interest rate	5.6%	Typical debt annual interest rate
Fraction of investment in bonds (percent debt vs. equity)	60%	Approximate remaining percentage of CAPEX with $1 billion sponsor equity per Matson (2024). Note that this source says that Fervo ultimately wants to target "15% sponsor equity, 15% bridge loan, and 70% construction to term loans," but this case study does not attempt to model that capital structure.
Exploration capital cost	$30 million	Estimate significantly higher exploration costs than default correlation in consideration of potential risks associated with second-/third-/fourth-of-a-kind EGS projects
Investment tax credit rate	30%	Same as 400-MWe case study (Fervo_Project_Cape-3)
Construction years	1	Calibrated to a 2- to 6-year construction time for a 1-GW plant (Yusifov and Enriquez 2025)

3.1.2 Technical and Engineering Parameters

Table 3. Technical and Engineering Parameters

Parameter	Input Value(s)	Source
Plant lifetime	30 years	30-year well life per Fervo Energy (2025a)
Construction time	1 year	Calibrated to a 2- to 6-year construction time for a 1-GW plant (Yusifov and Enriquez, 2025). Note that the "inflation rate during construction" parameter hedges against potential construction delays.
Well diameter	9⅝ inches	Next standard size up from 7 in., implied by announcement of "increasing casing diameter"
Flow rate per production well	107 kg/s	Fercho et al. (2025) models reservoir performance using 100 kg/s per well. The announced increased casing diameter implies higher flow rates, so the case study uses the maximum flow rate achieved at Cape Station of 107 kg/s per Business Wire (2024).
Number of doublets	59	Estimate based on extrapolation from previous case studies, including Project Red (https://gtp.scientificwebservices.com/geophires/?geophires-example-id=Fervo_Norbeck_Latimer_2023) and Fervo_Project_Cape-3 (https://gtp.scientificwebservices.com/geophires/?geophires-example-id=Fervo_Project_Cape-3)
Number of fractures per well	102	Estimate (Note this is not a direct GEOPHIRES input parameter but was used to calculate other case study GEOPHIRES input parameters, such as reservoir volume.)
Fracture separation	18 m	Per Norbeck, Gradl, and Latimer (2024): Lateral length is 4,700 ft = 1,432 m. Dividing 1,432 by 80 = approximately 18-m fracture spacing.
Fracture geometry	165.3 m × 165.3 m (square)	Extrapolated from 30 million ft² fracture surface area per well per Fercho et al. (2025).

Parameter	Input Value(s)	Source
Reservoir volume	5,919,217,617 m³	Calculated from fracture area (27,324.09 m²) × fracture separation (18 m) × targeted number of fractures per well (102)
Water loss rate	15%	Water loss rate is conservatively estimated to be between 10% and 20%. Other estimates and some simulations might suggest a significantly lower water loss rate than this conservative estimate. See Fervo Energy (2025a).
Maximum drawdown	0.0153	Tuned to keep minimum net electricity generation ≥500 MWe and thermal breakthrough requiring redrilling occurring every 5–10 years
Reservoir impedance	0.001565 GPa.s/m³	Yields approximately 15% initial pumping power/net installed power
Injection temperature	53.6°C	Calibrated with GEOPHIRES model-calculated reinjection temperature (Beckers and McCabe 2019a). Close to upper bound of Project Red injection temperatures (75–125°F; 23.89–51.67°C) (Norbeck and Latimer 2023).

3.1.3 Economic Results

Table 4. Economic Results

Metric	Result Value	Reference Value(s)	Source
Levelized cost of energy	\$81.1/MWh	\$80/MWh	Horne, Genter, and McClure (2025)
Project capital costs: total CAPEX	\$2.66 billion		
Project capital costs: \$/kW	\$5,000/kW (based on maximum net electricity generation)	\$5,000/kW; \$4,500/kW; \$3,000–\$6,000/kW	McClure (2024); Horne et al. (2025); Latimer (2025)
Well-drilling and completion costs	\$3.96 million/well; \$467.75 million total	<\$4 million/well	Latimer (2025)
Stimulation costs	\$4.6 million/well; \$542.8 million total	\$4.65 million/well (based on 46%:54% drilling:stimulation cost ratio)	Yusifov and Enriquez (2025)
Weighted average cost of capital	8.3%	8.3%	Matson 2024
After-tax internal rate of return	27.55%	15%–25%	Typical levered returns for energy projects

3.1.4 Technical and Engineering Results

Table 5. Technical and Engineering Results

Metric	Result Value	Reference Value(s)	Reference Source
Minimum net electricity generation	504 MW	500 MW	Fervo Energy (2025b). The 500-MW PPA is interpreted to mean that Cape Station's net electricity generation must never fall below 500 MWe.
Maximum net electricity generation	537 MW		
Maximum total electricity generation	615 MW		Actual maximum total generation could be bounded or constrained by modular power plant design not modeled in this case study. For example, a modular design with 50-MW units could constrain the maximum total generation to 600 MW.
Number of times redrilling	3	3–6	Redrilling expected to be required within 5–10 years of project start
Average production temperature	199°C	204°C, 190.6–198.6°C (optimal plant operating range)	Trent (2024); Norbeck, Gradl, and Latimer (2024)
Total fracture surface area per production well	2.787×10^6 m^2	2.787×10^6 m^2 (30 million ft^2 per well)	Fercho et al. (2025)
After-tax internal rate of return	27.55%	15%–25%	Typical levered returns for energy projects

4 Monte Carlo User Guide

Create a project with the following structure, including GEOPHIRES in requirements.txt and setting up venv with virtualenv:

```
├── GEOPHIRES-example1.txt
├── MC_GEOPHIRES_Settings_file.txt
├── main.py
├── requirements.txt
└── venv/
```

In main.py:

```
from pathlib import Path

from geophires_monte_carlo import GeophiresMonteCarloClient,
MonteCarloResult, MonteCarloRequest, SimulationProgram


def monte_carlo():
    client = GeophiresMonteCarloClient()

    result: MonteCarloResult = client.get_monte_carlo_result(
        MonteCarloRequest(
            SimulationProgram.GEOPHIRES,

            # Files from tests/geophires_monte_carlo_tests - copy these into
the same directory as main.py
            Path('GEOPHIRES-example1.txt').absolute(),
            Path('MC_GEOPHIRES_Settings_file.txt').absolute(),
            output_file=Path('MC_GEOPHIRES_Result.txt').absolute()
        )
    )

    with open(result.output_file_path, 'r') as result_output_file:
        result_display = result_output_file.read()
        print(f'MC result:\n{result_display}')

if __name__ == '__main__':
    monte_carlo()
```

To run:

```
(venv) python main.py
[...]

[2024-02-09 07:47:18][INFO] Complete geophires_monte_carlo.MC_GeoPHIRES3: main
MC result:
Electricity breakeven price, Project NPV, Gradient 1, Reservoir Temperature,
Utilization Factor, Ambient Temperature
38.81, -42.59, (Gradient 1:30.09736131122952;Reservoir
Temperature:320.2888549098197;Utilization Factor:0.9295528406892491;Ambient
Temperature:20.684620766378806;)
```

```
17.81, -42.76, (Gradient 1:39.47722802709689;Reservoir
Temperature:306.71578141214087;Utilization Factor:0.7604874092668568;Ambient
Temperature:20.39891267899405;)
9.91, -41.95, (Gradient 1:50.24142993501238;Reservoir
Temperature:311.3876336705825;Utilization Factor:0.8657162766204807;Ambient
Temperature:20.205604589516913;)
61.37, -43.34, (Gradient 1:28.230745766883796;Reservoir
Temperature:324.25115143107104;Utilization Factor:0.8308351836890867;Ambient
Temperature:20.615118153663598;)
8.76, -41.76, (Gradient 1:54.66070153603035;Reservoir
Temperature:319.6097066730564;Utilization Factor:0.855785650134492;Ambient
Temperature:19.359218133245772;)
7.58, -37.63, (Gradient 1:57.53774721757885;Reservoir
Temperature:318.6354560118773;Utilization Factor:0.9305717468323405;Ambient
Temperature:20.011047903204176;)
9.35, -41.03, (Gradient 1:51.20593175130416;Reservoir
Temperature:311.40737612727423;Utilization Factor:0.8876035819161642;Ambient
Temperature:19.968497775278948;)
18.11, -42.68, (Gradient 1:38.66016637029756;Reservoir
Temperature:310.20708430352124;Utilization Factor:0.7640202889998118;Ambient
Temperature:18.805190553693578;)
10.07, -40.41, (Gradient 1:47.876595779164845;Reservoir
Temperature:310.4061695000305;Utilization Factor:0.9228147348375185;Ambient
Temperature:20.119411582814514;)
23.08, -41.38, (Gradient 1:33.342513206728185;Reservoir
Temperature:305.48937077249826;Utilization Factor:0.9361923986407424;Ambient
Temperature:18.423715643246567;)
Electricity breakeven price:
     minimum: 7.58
     maximum: 61.37
     median: 13.94
     average: 20.48
     mean: 20.48
     standard deviation: 16.36
bin values (as percentage): [0.09295408 0.18590816 0.18590816 0.         0.
0.
 0.         0.         0.         0.18590816 0.         0.
 0.         0.         0.09295408 0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.09295408
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.09295408]
bin edges: [ 7.58    8.6558  9.7316 10.8074 11.8832 12.959  14.0348 15.1106 16.1864
 17.2622 18.338  19.4138 20.4896 21.5654 22.6412 23.717  24.7928 25.8686
 26.9444 28.0202 29.096  30.1718 31.2476 32.3234 33.3992 34.475  35.5508
 36.6266 37.7024 38.7782 39.854  40.9298 42.0056 43.0814 44.1572 45.233
 46.3088 47.3846 48.4604 49.5362 50.612  51.6878 52.7636 53.8394 54.9152
 55.991  57.0668 58.1426 59.2184 60.2942 61.37  ]
Project NPV:
     minimum: -43.34
     maximum: -37.63
     median: -41.86
     average: -41.55
```

```
     mean: -41.55
     standard deviation: 1.56
bin values (as percentage): [0.87565674 0.         0.         0.         0.
1.75131349
 0.87565674 0.         0.         0.         0.         0.
 0.87565674 0.87565674 0.         0.         0.         0.87565674
 0.         0.         0.87565674 0.         0.         0.
 0.         0.87565674 0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.87565674]
bin edges: [-43.34   -43.2258 -43.1116 -42.9974 -42.8832 -42.769  -42.6548 -42.5406
 -42.4264 -42.3122 -42.198  -42.0838 -41.9696 -41.8554 -41.7412 -41.627
 -41.5128 -41.3986 -41.2844 -41.1702 -41.056  -40.9418 -40.8276 -40.7134
 -40.5992 -40.485  -40.3708 -40.2566 -40.1424 -40.0282 -39.914  -39.7998
 -39.6856 -39.5714 -39.4572 -39.343  -39.2288 -39.1146 -39.0004 -38.8862
 -38.772  -38.6578 -38.5436 -38.4294 -38.3152 -38.201  -38.0868 -37.9726
 -37.8584 -37.7442 -37.63  ]
```

Monte Carlo simulations can also be run from the command line:

```
python -mgeophires_monte_carlo GEOPHIRESv3.py GEOPHIRES-example1.txt
MC_GEOPHIRES_Settings_file.txt MC_GEOPHIRES_Result.txt
```

5 Input Parameter Format

In the input text file, each parameter and value are provided by the user on a single line using one of the following two formats:

```
Parameter_name, parameter_value

Parameter_name, parameter_value, any comments
```

For example, to set the production well flow rate to 50 L/s, the user writes:

```
Production Flow Rate per Well, 50
```

Or when the user wants to include comments, e.g., to explain the units, they can write:

```
Production Flow Rate per Well, 50, production well flow rate in units of L/s
```

The user is free to choose any name for the input text file (in .txt format), but the user must assign that name to the parameter “fname” at the beginning in the GEOPHIRES Python code.

6 List of GEOPHIRES Input Parameters

The tables in this section list all 227 input parameters:

- Table 6: Reservoir Parameters (53)
- Table 7: Well Bore Parameters (40)
- Table 8: Surface Plant Parameters (24)
- Table 9: Economics Parameters (93)
- Table 10: HIP-RA-X Parameters (17).

Note that many parameters are interrelated and/or conditionally dependent on one another. Reviewing the relevant GEOPHIRES example(s) is strongly recommended to gain a working understanding of how to construct valid sets of input parameters. Future work on GEOPHIRES will include enhanced parameter schemas that encode dependencies and requirements.

6.1 Reservoir Parameters

Table 6. Reservoir Parameters

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Reservoir model	0: simple cylindrical; 1: multiple parallel fractures (Gringarten); 2: 1D linear heat sweep; 3: single-fracture m/a thermal drawdown; 4: annual percentage thermal drawdown; 5: user-provided temperature profile; 6: TOUGH2 simulator; 7: SUTRA; 8: SBT	None	Integer	4	0	8
Reservoir depth	Depth of the reservoir	Kilometer	Number	3.0	0.1	15
Maximum temperature	Maximum allowable reservoir temperature (e.g., due to drill bit or logging tools constraints). GEOPHIRES will cap the drilling depth to stay below this maximum temperature.	°C	Number	400.0	50	600
Number of segments	Number of rock segments from surface to reservoir depth with specific geothermal gradient	None	Integer	1	1	4
Gradients	Geothermal gradient(s)	°C/km	Array	[0.05, 0.0, 0.0, 0.0]	0.0	500.0
Gradient 1	Geothermal gradient 1 in rock segment 1	°C/km	Number	50	0.0	500.0
Gradient 2	Geothermal gradient 2 in rock segment 2	°C/km	Number	0.0	0.0	500.0
Gradient 3	Geothermal gradient 3 in rock segment 3	°C/km	Number	0.0	0.0	500.0
Gradient 4	Geothermal gradient 4 in rock segment 4	°C/km	Number	0.0	0.0	500.0
Thicknesses	Thicknesses of rock segments	Kilometer	Array	[100000.0, 0.01, 0.01, 0.01, 0.01]	0.01	100.0
Thickness 1	Thickness of rock segment 1	Kilometer	Number	2.0	0.01	100.0
Thickness 2	Thickness of rock segment 2	Kilometer	Number	0.01	0.01	100.0
Thickness 3	Thickness of rock segment 3	Kilometer	Number	0.01	0.01	100.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Thickness 4	Thickness of rock segment 4	Kilometer	Number	0.01	0.01	100.0
Reservoir volume option	Specifies how the reservoir volume and fracture distribution (for reservoir models 1 and 2) are calculated. The reservoir volume is used by GEOPHIRES to estimate the stored heat in place. The fracture distribution is needed as input for the EGS fracture-based reservoir models 1 and 2. 1: FRAC_NUM_SEP: Specify number of fractures and fracture separation. 2: RES_VOL_FRAC_SEP: Specify reservoir volume and fracture separation. 3: RES_VOL_FRAC_NUM: Specify reservoir volume and number of fractures. 4: RES_VOL_ONLY: Specify reservoir volume only.	None	Integer	3	1	4
Fracture shape	Specifies the shape of the (identical) fractures in a fracture-based reservoir: 1: circular fracture with known area; 2: circular fracture with known diameter; 3: square; 4: rectangular	None	Integer	1	1	4
Fracture area	Effective heat transfer area per fracture	m^2	Number	250000.0	1	100000000.0
Fracture height	Diameter (if fracture shape = 2) or height (if fracture shape = 3 or 4) of each fracture	Meter	Number	500.0	1	10000
Fracture width	Width of each fracture	Meter	Number	500.0	1	10000
Number of fractures	Number of identical parallel fractures in EGS fracture-based reservoir model	None	Integer	10	1	99999
Fracture separation	Separation of identical parallel fractures with uniform spatial distribution in EGS fracture-based reservoir	Meter	Number	50.0	1	10000.0
Reservoir volume	Geothermal reservoir volume	m^3	Number	125000000.0	10	1000000000000.0
Water loss fraction	Fraction of water lost in the reservoir defined as (total geofluid lost)/(total geofluid produced)	%	Number	0.0	0.0	0.99
Reservoir heat capacity	Constant and uniform reservoir rock heat capacity	J/kg/K	Number	1000.0	100	10000

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Reservoir density	Constant and uniform reservoir rock density	kg/m^3	Number	2700.0	100	10000
Reservoir thermal conductivity	Constant and uniform reservoir rock thermal conductivity	W/m/K	Number	3.0	0.01	100
Reservoir permeability	Constant and uniform reservoir permeability	m^2	Number	1e–13	1e–20	1e–05
Reservoir porosity	Constant and uniform reservoir porosity		Number	0.04	0.001	0.99
Surface temperature	Surface temperature used for calculating bottom-hole temperature (with geothermal gradient and reservoir depth)	°C	Number	15.0	-50	50
Drawdown parameter	Specify the thermal drawdown for reservoir models 3 and 4	1/year	Number	0.005	0	0.2
Cylindrical reservoir input depth	Depth of the inflow end of a cylindrical reservoir	Kilometer	Number	3.0	0.1	15
Cylindrical reservoir output depth	Depth of the outflow end of a cylindrical reservoir	Kilometer	Number	3.0	0.1	15
Cylindrical reservoir length	Length of cylindrical reservoir	Kilometer	Number	4.0	0.1	10.0
Cylindrical reservoir radius of effect	The radius of effect—the distance into the rock from the center of the cylinder that will be perturbed by at least 1°C	Meter	Number	30.0	0	1000.0
Cylindrical reservoir radius of effect factor	The radius of effect reduction factor—to account for the fact that we cannot extract 100% of the heat in the cylinder		Number	1.0	0.0	10.0
Drilled length	Depth of the inflow end of a cylindrical reservoir	Kilometer	Number	0.0	0.0	150

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Flow rate model	Must be 1 or 2: 1 means the user provides a constant mass flow rate; 2 means the user provides an Excel file with a mass flow rate profile.	None	Integer		1	2
Flow rate file	Excel file with a mass flow rate profile	None	String			
Injection temperature model	Must be 1 or 2: 1 means the user provides a constant injection temperature; 2 means the user provides an Excel file with an injection temperature profile.	None	Integer		1	2
Injection temperature file	Excel file with an injection temperature profile	None	String			
SBT accuracy desired	Must be 1, 2, 3, 4, or 5, with 1 the lowest accuracy and 5 the highest accuracy. The lowest accuracy runs fastest. The accuracy level impacts the number of discretizations for numerical integration and decision tree thresholds in the SBT algorithm.	None	Integer	1	1	5
SBT percent implicit Euler scheme	Should be between 0 and 1. Most stable is 1, which results in a fully implicit Euler scheme when calculating the fluid temperature at each time step. With a value of 0, the convective term is modeled using explicit Euler. A value of 0.5 would model the convective term 50% explicit and 50% implicit, which might be slightly more accurate than fully implicit.		Number	1.0	0.0	1.0
SBT initial time step count	The number of time steps in the first approximate 3 hours of the model	None	Integer	5	1	150
SBT final time step count	The number of time steps after the first approximate 3 hours of the model	None	Number	70	5	1000
SBT initial to final time step transition	The time in seconds at which the time arrays switch from closely spaced linear to logarithmic	Seconds	Number	9900	1	40000000

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
SBT generate wire frame graphics	Switch to control the generation of a wire frame drawing of an SBT wells configuration	None	Boolean	False		
SUTRA annual heat file name	SUTRA file with heat stored, heat supplied, and efficiency for each year	None	String	None		
SUTRA heat budget file name	SUTRA file with target heat and simulated heat for each SUTRA time step over lifetime	None	String	None		
SUTRA balance and storage well output file name	SUTRA file with well flow rate and temperature for each SUTRA time step over lifetime	None	String	None		
TOUGH2 executable path		None	String	xt2_eos1.exe		
TOUGH2 model/file name	File name of reservoir output in case reservoir model 5 is selected	None	String	None		
Reservoir thickness	Reservoir thickness for built-in TOUGH2 doublet reservoir model	Meter	Number	0.0	10	10000
Reservoir width	Reservoir width for built-in TOUGH2 doublet reservoir model	Meter	Number	0.0	10	10000

6.2 Wellbore Parameters

Table 7. Wellbore Parameters

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Number of production wells	Number of (identical) production wells	None	Integer	1	1	200
Number of Injection Wells	Number of (identical) injection wells	None	Integer	1	0	200
Number of doublets	Pass this parameter to set the number of production wells and number of injection wells to same value.	None	Integer	2	0	200
Production well diameter	Inner diameter of production wellbore (assumed constant along the wellbore) to calculate frictional pressure drop and wellbore heat transmission with Ramey's model	Inch	Number	8.0	1.0	30.0
Injection well diameter	Inner diameter of production wellbore (assumed constant along the wellbore) to calculate frictional pressure drop and wellbore heat transmission with Ramey's model	Inch	Number	8.0	1.0	30.0
Ramey production wellbore model	Select whether to use Ramey's model to estimate the geofluid temperature drop in the production wells.	None	Boolean	True		
Production wellbore temperature drop	Specify constant production well geofluid temperature drop in case Ramey's model is disabled.	°C	Number	5.0	-5.0	50.0
Injection wellbore temperature gain	Specify constant injection well geofluid temperature gain.	°C	Number	0.0	-5.0	50.0
Production flow rate per well	Geofluid flow rate per production well	kg/s	Number	50.0	1.0	500.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Reservoir impedance	Reservoir resistance to flow per well pair. For EGS-type reservoirs when the injection well is in hydraulic communication with the production well, this parameter specifies the overall pressure drop in the reservoir between the injection well and the production well (see docs).	$GPa.s/m^3$	Number	1000.0	0.0001	10000.0
Well separation	Well separation for built-in TOUGH2 doublet reservoir model. (Note that the default unit is inches.)	Meter	Number	39370	10.0	393700
Injection temperature	Constant geofluid injection temperature at injection wellhead.	°C	Number	70.0	0.0	200.0
Reservoir hydrostatic pressure	Reservoir hydrostatic far-field pressure. The default value is calculated with built-in modified Xie-Bloomfield-Shook equation.	kPa	Number	29430	100.0	100000.0
Production wellhead pressure	Constant production wellhead pressure; required if specifying productivity index	kPa	Number	446.02	0.0	10000.0
Injectivity index	Injectivity index defined as ratio of injection well flow rate over injection well outflow pressure drop (flowing bottom-hole pressure - hydrostatic reservoir pressure).	kg/s/bar	Number	10.0	0.01	10000.0
Productivity index	Productivity index defined as ratio of production well flow rate over production well inflow pressure drop (see docs)	kg/s/bar	Number	10.0	0.01	10000.0
Maximum drawdown	Maximum allowable thermal drawdown before redrilling of all wells into new reservoir (most applicable to EGS-type reservoirs with heat farming strategies)—e.g., a value of 0.2 means that all wells are redrilled after the production temperature (at the wellhead) has dropped by 20% of its initial temperature.		Number	1.0	0.0	1.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Advanced geothermal system	Set to true if the model is for an advanced geothermal system	None	Boolean	False		
Overpressure percentage	Enter the amount of pressure over the hydrostatic pressure in the reservoir (100% = hydrostatic).	%	Number	100.0	-1.8e+30	1.8e+30
Overpressure depletion rate	Enter the amount of pressure over the hydrostatic pressure in the reservoir (100% = hydrostatic).	%/yr	Number	0.0	-1.8e+30	1.8e+30
Injection reservoir temperature	Enter the temperature of the injection reservoir (100°C).	°C	Number	100.0	-1.8e+30	1.8e+30
Injection reservoir depth	Enter the depth of the injection reservoir (1000 m).	Meter	Number	1000.0	-1.8e+30	1.8e+30
Injection reservoir initial pressure	Enter the depth of the injection reservoir initial pressure (use lithostatic pressure).	kPa	Number	0.0	-1.8e+30	1.8e+30
Injection reservoir inflation rate	Enter the rate at which the pressure increases per year in the injection reservoir (1000 kPa/yr).	kPa/yr	Number	1000.0	-1.8e+30	1.8e+30
Closed-loop configuration	1: utube; 2: coaxial; 3: vertical; 4: L; 5: EavorLoop	None	Integer	3	1	5
Well geometry configuration	1: utube; 2: coaxial; 3: vertical; 4: L; 5: EavorLoop	None	Integer	3	1	5
Water thermal conductivity	Water thermal conductivity	W/m/K	Number	0.6	0.0	100.0
Heat transfer fluid	1: water; 2: sCO_2	None	Integer	1	1	2
Nonvertical length per multilateral section		Meter	Number	1000.0	50.0	20000.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Nonvertical wellbore diameter	Nonvertical wellbore diameter	Meter	Number	0.156	0.01	100.0
Number of multilateral sections	Number of nonvertical wellbore sections, i.e., laterals or horizontals. Note that this is the total number of sections for the entire project and not the number of sections per well. For example, a project with 2 injectors and 2 producers with 3 laterals per well should set the number of multilateral sections = 2 * 2 * 3 = 12.	None	Integer	0	0	1199
Multilaterals cased	If set to true, casing and cementing are assumed to comprise 50% of drilling costs (doubling cost compared to uncased).	None	Boolean	False		
Closed-loop calculation start year	Closed-loop calculation start year	yr	Number	0.01	0.01	100.0
Vertical section length	Length/depth to the bottom of the vertical wellbores	Meter	Number	2000.0	0.01	10000.0
Vertical wellbore spacing	Horizontal distance between vertical wellbores	Meter	Number	100.0	0.01	10000.0
Lateral spacing	Horizontal distance between laterals	Meter	Number	100.0	0.01	10000.0
Lateral inclination angle	Inclination of the lateral section, where 0 degrees would mean vertical, while 90 degrees is pure horizontal	Degrees	Number	20.0	0.0	89.999999
Discretization length	Distance between sample point along length of model	Meter	Number	250.0	0.01	10000.0
Junction depth	Vertical depth where the different laterals branch out (where the multilateral section starts, second deepest depth of model)	Meter	Number	4000.0	1000	15000.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Lateral end point depth	Vertical depth where the lateral section ends (tip of the multilateral section, deepest depth of model)	Meter	Number	7000.0	1000	15000.0

6.3 Surface Plant Parameters

Table 8. Surface Plant Parameters

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
End-use option	Select the end-use application of the geofluid heat: 1: electricity; 2: direct-use heat; 31: cogeneration topping cycle, heat sales considered as extra income; 32: cogeneration topping cycle, electricity sales considered as extra income; 41: cogeneration bottoming cycle, heat sales considered as extra income; 42: cogeneration bottoming cycle, electricity sales considered as extra income; 51: cogeneration parallel cycle, heat sales considered as extra income; 52: cogeneration parallel cycle, electricity sales considered as extra income	None	Integer	1	1	52
Power plant type	Specify the type of physical plant. 1: subcritical ORC; 2: supercritical ORC; 3: single flash; 4: double flash; 5: absorption chiller; 6: heat pump; 7: district heating; 8: reservoir thermal energy storage; 9: industrial	None	Integer	1	1	9
Circulation pump efficiency	Specify the overall efficiency of the injection and production well pumps.	%	Number	0.75	0.1	1.0
Utilization factor	Ratio of the time the plant is running in normal production in a 1-year time period. Synonymous with capacity factor		Number	0.9	0.1	1.0
End-use efficiency factor	Constant thermal efficiency of the direct-use application		Number	0.9	0.1	1.0
CHP fraction	Fraction of produced geofluid flow rate going to direct-use heat application in CHP parallel cycle		Number	0.5	0.0001	0.9999

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
CHP bottoming entering temperature	Power plant entering geofluid temperature used in CHP bottoming cycle	°C	Number	150.0	0	400
Ambient temperature	Ambient (or dead-state) temperature used for calculating power plant utilization efficiency	°C	Number	15.0	-50	50
Plant lifetime	System lifetime	Year	Integer	30	1	100
Surface piping length		Kilometer	Number	0.0	0	100
Plant outlet pressure	Constant plant outlet pressure equal to injection well pump(s) suction pressure	kPa	Number	100.0	0.01	15000.0
Electricity rate	Price of electricity to calculate pumping costs in direct-use heat-only mode or revenue from electricity sales in CHP mode	USD/kWh	Number	0.07	0.0	1.0
Heat rate	Price of heat to calculate revenue from heat sales in CHP mode	USD/kWh	Number	0.02	0.0	1.0
Construction years	Number of years spent in construction (assumes whole years, no fractions). Capital costs are spread evenly over construction years—e.g., if total capital costs are $500 million and there are 2 construction years, then $250 million will be spent in both the first and second construction years.	None	Integer	1	1	14
Working fluid heat capacity	Heat capacity of the working fluid	J/kg/K	Number	4200.0	0.0	10000.0
Working fluid density	Density of the working fluid	kg/m^3	Number	1000.0	0.0	10000.0
Working fluid thermal conductivity	Thermal conductivity of the working fluid	W/m/K	Number	0.68	0.0	10.0
Working fluid dynamic viscosity	Dynamic viscosity of the working fluid	PaSec	Number	0.0006	0.0	1
Dead-state pressure		Pa	Number	100000.0	80000.0	110000.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Isentropic efficiency for CO_2 turbine			Number	0.9	0.8	1.0
Generator conversion efficiency			Number	0.98	0.8	1.0
Isentropic efficiency for CO_2 compressor			Number	0.9	0.8	1.0
CO_2 temperature decline with cooling		°C	Number	12.0	0.0	15.0
CO_2 turbine outlet pressure		bar	Number	81.0	75.0	200.0

6.4 Economics Parameters

Table 9. Economics Parameters

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Economic model	Specify the economic model to calculate the levelized cost of energy: 1: fixed charge rate; 2: standard levelized cost; 3: BICYCLE; 4: simple (CLGS); 5: SAM single-owner PPA	None	Integer	2	1	5
Reservoir stimulation capital cost	Total reservoir stimulation capital cost, including indirect costs and contingency	MUSD	Number	-1.0	0	1000
Reservoir stimulation	Reservoir stimulation capital cost per injection well before indirect costs and contingency	MUSD	Number	1.25	0	100

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
capital cost per injection well						
Reservoir stimulation capital cost per production well	Reservoir stimulation capital cost per production well before indirect costs and contingency. By default, only the injection wells are assumed to be stimulated unless this parameter is provided.	MUSD	Number	0	0	100
Reservoir stimulation Capital cost adjustment factor	Multiplier for reservoir stimulation capital cost correlation		Number	1.0	0	10
Reservoir stimulation indirect capital cost percentage	The indirect capital cost for reservoir stimulation, calculated as a percentage of the direct cost. (Not applied if reservoir stimulation capital cost is provided.)	%	Number	5	0	100
Exploration capital cost	Total exploration capital cost	MUSD	Number	-1.0	0	1000
Exploration capital cost adjustment Factor	Multiplier for built-in exploration capital cost correlation		Number	1.0	0	10
Well-drilling and completion capital cost	Well-drilling and completion capital cost per well including indirect costs and contingency. Applied to production wells; also applied to injection wells unless injection well-drilling and completion capital cost is provided.	MUSD	Number	-1	0	200
Injection well-drilling and completion capital cost	Injection well-drilling and completion capital cost per well including indirect costs and contingency	MUSD	Number	-1	0	200
Well-drilling and completion capital cost	Well-drilling and completion capital cost adjustment factor. Applies to production wells; also applies to		Number	1.0	0	10

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
adjustment factor	injection wells unless a value is provided for injection well-drilling and completion capital cost adjustment factor.					
Injection well-drilling and completion capital cost Adjustment factor	Injection well-drilling and completion capital cost adjustment factor. If it is not provided, this value will be automatically set to the same value as the well-drilling and completion capital cost adjustment factor.		Number	1.0	0	10
Wellfield O&M cost	Total annual wellfield O&M cost	MUSD/yr	Number	-1.0	0	100
Wellfield O&M cost adjustment factor	Multiplier for built-in wellfield O&M cost correlation		Number	1.0	0	10
Surface plant capital cost	Total surface plant capital cost	MUSD	Number	-1.0	0	10000
Surface plant capital cost adjustment factor	Multiplier for built-in surface plant capital cost correlation		Number	1.0	0	10
Capital cost for power plant for electricity generation		USD/kW	Number	3000	0.0	10000.0
Field-gathering system capital cost	Total field-gathering system capital cost	MUSD	Number	-1.0	0	100
Field-gathering system capital cost adjustment factor	Multiplier for built-in field-=gathering system capital cost correlation		Number	1.0	0	10
Surface plant O&M cost	Total annual surface plant O&M cost	MUSD/yr	Number	-1.0	0	100

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Surface plant O&M cost Adjustment factor	Multiplier for built-in surface plant O&M cost correlation		Number	1.0	0	10
Water cost	Total annual makeup water cost	MUSD/yr	Number	-1.0	0	100
Water cost adjustment factor	Multiplier for built-in makeup water cost correlation		Number	1.0	0	10
Total capital cost	Total initial capital cost	MUSD	Number	-1.0	0	100000.0
Total O&M cost	Total initial O&M cost	MUSD/yr	Number	-1.0	0	100
Time steps per year	Number of internal simulation time steps per year	None	Integer	4	1	100
Fixed charge rate	Fixed charge rate used in the fixed charge rate model		Number	0.1	0.0	1.0
Discount rate	Discount rate used in the standard levelized cost model and SAM economic models. The discount rate is synonymous with the fixed internal rate. If one is provided, the other's value will be automatically set to the same value.		Number	0.07	0.0	1.0
Discount initial-year cash flow	Whether to discount cashflow in the initial project year when calculating NPV. The default value of false conforms to NREL's standard convention for NPV calculation (Short et al. 1995). A value of true will, by contrast, cause the NPV calculation to follow the convention used by Excel, Google Sheets, and other common spreadsheet software. Although NREL's NPV convention might typically be considered more technically correct, Excel-style NPV calculation might be preferred for familiarity or compatibility with existing business processes. For further details, see github.com/NREL/GEOPHIRES-X/discussions/344.	None	Boolean	False		

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Fraction of investment in bonds	Fraction of geothermal project financing through bonds (debt)		Number	0.5	0.0	1.0
Inflated bond interest rate	Inflated bond interest rate (see docs)		Number	0.05	0.0	1.0
Inflated equity interest rate	Inflated equity interest rate (see docs)		Number	0.1	0.0	1.0
Inflation rate	Inflation rate		Number	0.02	0.0	1.0
Combined income tax rate	Combined income tax rate (see docs)		Number	0.02	0.0	1.0
Gross revenue tax rate	Gross revenue tax rate (see docs)		Number	0.02	0.0	1.0
Investment tax credit rate	Investment tax credit rate (see docs)		Number	0.0	0.0	1.0
Property tax rate	Property tax rate (see docs)		Number	0.0	0.0	1.0
Inflation rate during construction	The total inflation rate applied to capital costs over the entire construction period, entered as a fraction (e.g., 0.15 for 15%). This value defines the accrued financing during the construction output. Note: For SAM economic models, if this parameter is not provided, inflation costs will be automatically calculated by compounding the inflation rate over construction years.	%	Number	0.0	0.0	1.0
Contingency percentage	The contingency percentage applied to the direct capital costs for stimulation, field-gathering system, exploration, and surface plant. (Note: Well-drilling and completion costs do not have a contingency applied and are not affected by this parameter.)	%	Number	15.0	0.0	100.0
Well-drilling cost correlation	Select the built-in well-drilling and completion cost correlation: 1: vertical small diameter, baseline; 2: deviated small diameter, baseline; 3: vertical large	None	Integer	10	1	17

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
	diameter, baseline; 4: deviated large diameter, baseline; 5: simple (per-meter cost); 6: vertical small diameter, intermediate1; 7: vertical small diameter, intermediate2; 8: deviated small diameter, intermediate1; 9: deviated small diameter, intermediate2; 10: vertical large diameter, intermediate1; 11: vertical large diameter, intermediate2; 12: deviated large diameter, intermediate1; 13: deviated large diameter, intermediate2; 14: vertical open hole, small diameter, ideal; 15: deviated liner, small diameter, ideal; 16: vertical open hole, large diameter, ideal; 17: deviated liner, large diameter, ideal. Baseline correlations (1—4) are from NREL's 2025 cost curve update (Akindipe and Witter 2025). Intermediate and ideal correlations (6–17) are from GeoVision (DOE 2019).					
Do add-on calculations	Set to true for the add-on economic calculations to be made	None	boolean	False		
Do carbon price calculations	Set to true for the carbon credit economic calculations to be made	None	boolean	False		
Do S-DAC-GT calculations	Set to true for the S-DAC-GT economic calculations to be made	None	boolean	False		
All-in vertical drilling costs	Set user-specified all-in cost per meter of vertical drilling, including drilling, casing, cement, and insulated insert.	USD/m	Number	1000.0	0.0	10000.0
All-in nonvertical drilling costs	Set user-specified all-in cost per meter of nonvertical drilling, including drilling, casing, cement, and insulated insert.	USD/m	Number	1300.0	0.0	15000.0
Well-drilling and completion indirect capital cost percentage	The indirect capital cost for well drilling and completion of all wells (the wellfield), calculated as a percentage of the direct cost	%	Number	5	0	100
Indirect capital cost percentage	The indirect cost percentage applied to capital costs (default 12%). This value is used for all cost categories—including surface plant, field-gathering system, and exploration—except when a category-specific indirect	%	Number	12	0	100

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
	cost parameter is defined or provided. Wellfield costs use well-drilling and completion indirect capital cost percentage (default 5%). Stimulation costs use reservoir stimulation indirect capital cost percentage (default 5%).					
Absorption chiller capital cost	Absorption chiller capital cost	MUSD	Number	5	0	100
Absorption chiller O&M cost	Absorption chiller O&M cost	MUSD/yr	Number	1	0	100
Heat pump capital cost	Heat pump capital cost	MUSD	Number	5	0	100
Peaking fuel cost rate	Price of peaking fuel for peaking boilers	USD/kWh	Number	0.034	0.0	1.0
Peaking boiler efficiency	Peaking boiler efficiency		Number	0.85	0	1
Peaking boiler cost per kW	Peaking boiler cost per kilowatt of maximum peaking boiler demand	USD/kW	Number	65	0	1000
District heating piping cost rate	District heating piping cost rate ($/m)	USD/m	Number	1200	0	10000
Total district heating network cost	Total district heating network cost ($M)	MUSD	Number	10	0	1000
District heating O&M cost	Total annual district heating O&M cost ($M/year)	MUSD/yr	Number	1	0	100
District heating network piping length	District heating network piping length (km)	Kilometer	Number	10.0	0	1000
District heating road length	District heating road length (km)	Kilometer	Number	10.0	0	1000

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
District heating land area	District heating land area (km^2)	km^2	Number	10.0	0	1000
District heating population	Specify the population in the district heating network.	None	Number	200	0	1000000
Starting heat sale price		USD/kWh	Number	0.025	0	100
Ending heat sale price		USD/kWh	Number	0.025	0	100
Heat escalation start year	Number of years after the start of the project and before the start of escalation	yr	Integer	5	0	100
Heat escalation rate per year	Additional cost per year of price after escalation starts	USD/kWh	Number	0.0	0.0	100.0
Starting electricity sale price		USD/kWh	Number	0.055	0	100
Ending electricity sale price	The maximum price to which the electricity sale price can escalate. For example, if the starting electricity sale price = 0.10 USD/kWh and the electricity escalation rate = 0.01 USD/kWh/yr, the electricity price will reach 0.15 USD/kWh after 4 years of escalation. The price will then remain at 0.15 USD/kWh for the remaining years of the project lifetime. If the ending electricity sale price is not reached by escalation during the project lifetime, then the value will have no effect beyond allowing escalation to occur every year.	USD/kWh	Number	0.055	0	100
Electricity escalation start year	Number of years after the start of the project and before the start of escalation	yr	Integer	5	0	100
Electricity escalation rate per year	Additional cost per year of price after escalation starts	USD/kWh	Number	0.0	0.0	100.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Starting cooling sale price		USD/kWh	Number	0.025	0	100
Ending cooling sale price		USD/kWh	Number	0.025	0	100
Cooling escalation start year	Number of years after the start of the project and before the start of escalation	yr	Integer	5	0	100
Cooling escalation rate per year	Additional cost per year of price after escalation starts	USD/kWh	Number	0.0	0.0	100.0
Starting carbon credit value		USD/lb	Number	0.0	0	1000
Ending carbon credit value		USD/lb	Number	0.0	0	1000
Carbon escalation start year	Number of years after the start of the project and before the start of carbon incentives	yr	Integer	0	0	100
Carbon escalation rate per year	Additional value per year of price after escalation starts	USD/lb	Number	0.0	0.0	100.0
Current grid CO_2 production	CO_2 intensity of the grid (how much CO_2 is produced per kWh of electricity produced (0.93916924 lbs/kWh for the Electric Reliability Council of Texas))	lbs/kWh	Number	0.93916924	0	50000
CO_2 produced by natural gas	CO_2 intensity of burning natural gas (how much CO_2 is produced per kWh of heat produced (0.070324961 lbs/kWh; www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references))	lbs/kWh	Number	0.070324961	0	50000
Annual license fees, etc.		MUSD	Number	0.0	-1000.0	1000.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
One-time flat license fees, etc.		MUSD	Number	0.0	-1000.0	1000.0
Other incentives		MUSD	Number	0.0	-1000.0	1000.0
Tax relief per year	Fixed percentage reduction in annual tax rate	%	Number	0.0	0.0	100.0
One-time grants, etc.		MUSD	Number	0.0	-1000.0	1000.0
Fixed internal rate	Fixed internal rate (used in NPV calculation). The fixed internal rate is synonymous with the discount rate. If one is provided, the other's value will be automatically set to the same value.	%	Number	7.0	0.0	100.0
CHP electrical plant cost allocation ratio	CHP electrical plant cost allocation ratio (cost electrical plant/total CAPEX)		Number	-1.0	0.0	1.0
Production tax credit electricity	Production tax credit for electricity in $/kWh	USD/kWh	Number	0.04	0.0	10.0
Production tax credit heat	Production tax credit for heat in $/MMBTU	USD/MMBTU	Number	0.0	0.0	100.0
Production tax credit cooling	Production tax credit for cooling in $/MMBTU	USD/MMBTU	Number	0.0	0.0	100.0
Production tax credit duration	Production tax credit for duration in years	yr	Integer	10	0	99
Production tax credit inflation adjusted	Production tax credit inflation adjusted	None	boolean	False		
Estimated jobs created per MW	Estimated jobs created per megawatt of electricity produced, per geothermal.org/resources/geothermal-basics	None	Number	2.13	-1.8e+30	1.8e+30

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
of electricity produced						
O&M cost of surface plant			Number	0.015	0.0	0.2
Capital cost for surface plant for direct-use system		USD/kW	Number	100.0	0.0	10000.0
Add-on nickname	If using multiple add-ons, either (1) specify this value as an array, or (2) use multiple parameters suffixed with a number, e.g., 'AddOn Nickname 1', 'AddOn Nickname 2'.	None	Array	[]	0.0	1000.0
Add-on CAPEX	If using multiple add-ons, either (1) specify this value as an array, or (2) use multiple parameters suffixed with a number, e.g., 'AddOn CAPEX 1', 'AddOn CAPEX 2'.	MUSD	Array	[]	0.0	1000.0
Add-on operational expenditures (OPEX)	Annual operating cost. If using multiple add-ons, either (1) specify this value as an array, or (2) use multiple parameters suffixed with a number, e.g., 'AddOn OPEX 1', 'AddOn OPEX 2'.	MUSD/yr	Array	[]	0.0	1000.0
Add-on electricity gained	Annual electricity gained. If using multiple add-ons, either (1) specify this value as an array, or (2) use multiple parameters suffixed with a number, e.g., 'AddOn Electricity Gained 1', 'AddOn Electricity Gained 2'.	kW/yr	Array	[]	0.0	1000.0
Add-on heat gained	Annual heat gained. If using multiple add-ons, either (1) specify this value as an array, or (2) use multiple parameters suffixed with a number, e.g., 'AddOn Heat Gained 1', 'AddOn Heat Gained 2'.	kW/yr	Array	[]	0.0	1000.0
Add-on profit gained	Annual profit gained. If using multiple add-ons, either (1) specify this value as an array, or (2) use multiple parameters suffixed with a number, e.g., 'AddOn Profit Gained 1', 'AddOn Profit Gained 2'.	MUSD/yr	Array	[]	0.0	1000.0

6.5 HIP-RA-X Parameters

Table 10. HIP-RA-X Parameters

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
Reservoir temperature	Reservoir temperature	°C	Number	150.0	50	1000
Rejection temperature	Rejection temperature	°C	Number	25.0	0.1	200
Reservoir porosity	Reservoir porosity	%	Number	18.0	0.0	100.0
Reservoir area	Reservoir area	km^2	Number	81.0	0.0	10000.0
Reservoir thickness	Reservoir thickness	Kilometer	Number	0.286	0.0	10000.0
Reservoir life cycle	Reservoir life cycle	Year	Integer	30	1	100
Rock heat capacity	Rock heat capacity	kJ/km^3C	Number	2840000000000.0	0.0	100000000000000.0
Fluid-specific heat capacity	Specific heat capacity of water	kJ/kgC	Number	-1.0	3.0	10.0
Density of reservoir fluid	Density of water	kg/km^3	Number	-1.0	100000000000.0	10000000000000.0
Density of reservoir rock	Density of rock	kg/km^3	Number	2550000000000.0	100000000000.0	10000000000000.0
Rock recoverable heat	Percentage of heat that is recoverable from the rock in the reservoir: 0.66 for high-T reservoirs, 0.43 for low-T reservoirs (Garg and Combs 2011)		Number	-1.0	0.0	1.0
Fluid recoverable heat	Percentage of heat that is recoverable from the fluid in the reservoir: 0.66 for high-T		Number	-1.0	0.0	1.0

Name	Description	Preferred Units	Default Value Type	Default Value	Min	Max
	reservoirs, 0.43 for low-T reservoirs (Garg and Combs 2011)					
Recoverable fluid factor	Percentage of fluid that is recoverable from the reservoir (0.5 = 50%)		Number	0.5	0.0	1.0
Reservoir depth	Depth to top of reservoir (km). Calculated based on an assumed gradient and the reservoir temperature if no value given	Kilometer	Number	-1.0	0.001	15.0
Reservoir pressure	Pressure of the reservoir (in MPa). Calculated assuming hydrostatic pressure and reservoir depth and water density if no value given	MPa	Number	-1.0	0.0	10000.0
Recoverable heat from rock	Percentage of heat that is recoverable from the rock (0.75 = 75%)		Number	0.75	0.0	1.0
HTML output file	Provide an HTML output name to have HTML output (no output if not provided)	None	String	HIP.html		
Reservoir width	Reservoir width for built-in TOUGH2 doublet reservoir model	Meter	Number	0.0	10	10000

7 SAM Economic Models

GEOPHIRES SAM economic models leverage NREL's SAM financial models by transforming GEOPHIRES parameters into SAM parameters and running the corresponding SAM model with PySAM. Full documentation is available at nrel.github.io/GEOPHIRES-X/SAM-Economic-Models.html.

Table 11. SAM Economic Models

GEOPHIRES Parameter(s)	SAM Category	SAM Input(s)	SAM Module(s)	SAM Parameter Name(s)	Comment
Maximum total electricity generation	Generation profile	Nameplate capacity	Singleowner	system_capacity	
Utilization factor	Generation profile	Nominal capacity factor	Singleowner	user_capacity_factor	
Net electricity generation	AC degradation	Annual AC degradation rate schedule	Utilityrate5	Degradation	The percentage difference of each year's net electricity generation from the maximum total electricity generation is input into SAM as the degradation rate schedule to match the SAM generation profile to GEOPHIRES.
Total CAPEX × (1 + inflation rate during construction)	Installation costs	Total installed cost	Singleowner	total_installed_cost	Inflation during construction is treated as an indirect engineering, procurement, and construction capital cost percentage. Note that unlike the BICYCLE economic model's total CAPEX, the SAM economic model's total CAPEX is the total installed cost and does not subtract the

GEOPHIRES Parameter(s)	SAM Category	SAM Input(s)	SAM Module(s)	SAM Parameter Name(s)	Comment
					investment tax credit value (if present).
Total O&M cost, inflation rate	Operating costs	Fixed operating cost, escalation rate set to inflation rate × -1	Singleowner	om_fixed, om_fixed_escal	
Plant lifetime	Financial parameters → analysis parameters	Analysis period	CustomGeneration, Singleowner	CustomGeneration.analysis_period, Singleowner.term_tenor	
Inflation rate	Financial parameters → analysis parameters	Inflation rate	Utilityrate5	inflation_rate	
Discount rate	Financial parameters → analysis parameters	Real discount rate	Singleowner	real_discount_rate	
Combined income tax rate	Financial parameters → project tax and insurance rates	Federal income tax rate: minimum of {21%, CITR}; and state income tax rate: maximum of {0%; CITR - 21%}	Singleowner	federal_tax_rate, state_tax_rate	GEOPHIRES does not have separate parameters for federal and state income taxes, so the rates are split from the combined rate based on an assumption of a maximum federal tax rate of 21% and the residual amount being the state tax rate.
Property tax rate	Financial parameters	Property tax rate	Singleowner	property_tax_rate	

GEOPHIRES Parameter(s)	SAM Category	SAM Input(s)	SAM Module(s)	SAM Parameter Name(s)	Comment
Fraction of investment in bonds	Financial parameters → project term debt	Debt percentage	Singleowner	debt_percent	
Inflated bond interest rate	Financial parameters → project term debt	Annual interest rate	Singleowner	term_int_rate	
Starting electricity sale price, ending electricity sale price, electricity escalation rate per year, electricity escalation start year	Revenue	PPA price	Singleowner	ppa_price_input	GEOPHIRES's pricing model is used to create a PPA price schedule that is passed to SAM.
Investment tax credit rate	Incentives → investment tax credit	Federal → percentage (%)	Singleowner	itc_fed_percent	
Production tax credit electricity	Incentives → production tax credit	Federal → amount ($/kWh)	Singleowner	ptc_fed_amount	
Production tax credit duration	Incentives → production tax credit	Federal → term (years)	Singleowner	ptc_fed_term	
Production tax credit inflation adjusted, inflation rate	Incentives → production tax credit	Federal → escalation (%/yr)	Singleowner	ptc_fed_escal	If production tax credit inflation adjusted = true, GEOPHIRES set's SAM's production tax credit escalation rate to the inflation rate. SAM applies the escalation rate to years two and later of the

GEOPHIRES Parameter(s)	SAM Category	SAM Input(s)	SAM Module(s)	SAM Parameter Name(s)	Comment
					project cash flow. Note that this produces escalation rates that are similar to inflation-adjusted equivalents, but not exactly equal.
Other incentives + one-time grants, etc.	Incentives → investment-based incentive (IBI)	Other → amount ($)	Singleowner	ibi_oth_amount	

7.1 Using SAM Economic Models With Existing GEOPHIRES Inputs

In many cases, all the user needs to do to use the SAM economic models for existing GEOPHIRES inputs is to change the economic model parameter value. For example, if the GEOPHIRES .txt file contained the following:

```
# *** Financial Parameters ***
Economic Model, 2, -- Standard Levelized Cost Model
Discount Rate, .05
Plant Lifetime, 25
```

The user would change it to:

```
# *** Financial Parameters ***
Economic Model, 5, -- SAM Single Owner PPA Economic Model
Discount Rate, .05
Plant Lifetime, 25
```

For inputs with the BICYCLE economic model, such as the following:

```
# *** Financial Parameters ***
Economic Model, 3, -- BICYCLE
Inflated Equity Interest Rate, .08
Plant Lifetime, 30
```

Change the economic model and replace the inflated equity interest rate with a suitable discount rate and inflation rate:

```
# *** Financial Parameters ***
Economic Model, 5, -- SAM Single Owner PPA Economic Model
Discount Rate, .08
Inflation Rate, .03
Plant Lifetime, 30
```

7.1.1 Recreating SAM Economic Model Results in the SAM Desktop Application

First, open src/geophires_sam_economics/Generic_400_MWe.sam in the SAM desktop application.

Next, run GEOPHIRES for the input, e.g.:

```
python -mgeophires_x my-geophires-input.txt
```

Then, check src/geophires_x/all_messages_conf.log for the SAM economics parameter mapping entry:

```
23-05-2025 10:09:35 : INFO : EconomicsSam : calculate_sam_economics : 151 : (Process
Details : (1378, MainProcess), Thread Details : (8589068352, MainThread)): SAM
Economics Parameter Mapping:
```

```
-----------------  --------------------  --------------------------------------------
-------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------
-------------

SAM Module         Parameter             Value

Custom Generation  analysis_period       20

Custom Generation  user_capacity_factor  90.0

Utility Rate       inflation_rate        2.0

Utility Rate       degradation           [1.2734946600673935, 0.7001040275842613,
0.5267634676194525, 0.4244824247238818, 0.3529717582311231, 0.29852256883429373,
0.2548483024454293, 0.21855974702202877, 0.18762922644042462, 0.1607514026827296,
0.13703877682895466, 0.11586181507372084, 0.09675857340703789, 0.07938054662917803,
0.06345865490418974, 0.0487810281945756, 0.03517801101748528, 0.02251175220012943,
0.010668799824934945, 0.0]

Single Owner       analysis_period       20

Single Owner       total_installed_cost  264606243.76608825

Single Owner       om_fixed              [7193902.821741002]

Single Owner       om_fixed_escal        -2.0

Single Owner       system_capacity       59020.69007804236

Single Owner       federal_tax_rate      [21.0]

Single Owner       state_tax_rate        [7.0]

Single Owner       itc_fed_percent       [30.0]

Single Owner       property_tax_rate     0.0

Single Owner       ppa_price_input       [0.08, 0.08, 0.08322, 0.08644, 0.08966,
0.09288, 0.0961, 0.09932, 0.10254, 0.10576, 0.10898000000000001, 0.1122, 0.11542,
0.11864, 0.12186, 0.12508, 0.1283, 0.13152, 0.13474, 0.13796]

Single Owner       debt_percent          40.0

Single Owner       real_discount_rate    8.0

Single Owner       term_tenor            20

Single Owner       term_int_rate         5.0

Single Owner       ibi_oth_amount        0.0
```

```
----------------- ------------------- ----------------------------------------
------------------------------------------------------------------------------
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```

The user can then manually enter the parameters from the logged mapping into the SAM desktop application.

8 Extending GEOPHIRES-X

Determine which object or objects (reservoir, wellbores, surface plant, and/or economics) will be extended.

In this example, the *Economics* object is extended.

Create a new file with the same name as the class to be used.

In this example, the file is named EconomicsAddOns.

Add the file to the project if working in a development environment such as PyCharm or Visual Studio.

In the models class, add an import statement for the newly created class.
For this example, the import line is:

```
from EconomicsAddons import *
```

In the __init__ method of the models class, initialize the new class. In this case, the line looks like this:

```
self.economics = EconomicsAddOns(self)
```

Fill that new file with this template, changing the class name and imports as appropriate:

```
import math
import sys
import numpy as np
import numpy_financial as npf
import Model
import Economics
from OptionList import EndUseOptions
from Parameter import intParameter, floatParameter, listParameter, OutputParameter
from Units import *

class EconomicsAddOns(Economics.Economics):
    def __init__(self, model):
        model.logger.info("Init " + str(__class__) + ": " + sys._getframe(
).f_code.co_name)

        #Set up all the Parameters that will be predefined by this class using
        #the different types of parameter classes.
        # [...]

        #local variables that need initialization
        # [...]

        #results
        # [...]
```

```
        model.logger.info("Complete "+ str(__class__) + ": " + sys._getframe(
).f_code.co_name)

    def __str__(self):
        return "EconomicsAddOns"

    def read_parameters(self, model) -> None:
        model.logger.info("Init " + str(__class__) + ": " + sys._getframe(
).f_code.co_name)

        #Deal with all the parameter values that the user has provided.
        # [...]

        model.logger.info("complete "+ str(__class__) + ": " + sys._getframe(
).f_code.co_name)

    def Calculate(self, reserv, wellbores, surfaceplant, model) -> None:
        model.logger.info("Init " + str(__class__) + ": " + sys._getframe(
).f_code.co_name)

        #This is where all the calculations are made using all the values that
        #have been set.
        # [...]

        model.logger.info("complete "+ str(__class__) + ": " + sys._getframe(
).f_code.co_name)
```

The class definition must include a reference to the parent class: `class EconomicsAddOns(Economics.Economics)`. In this case, the parent class is economics. Replace this with the appropriate parent class as required. Multiple inheritances are also supported, but they are not required in this example.

The import command `from the Economics import *` imports all attributes and methods from the parent class. Adjust the import statement to reference the appropriate class.

The model class is passed into all these methods. This is the wrapper class in which all objects reside. It contains shared values accessible to all classes, such as the logger.

For the __init__ method, determine whether the parent class should be initialized. Initializing the parent creates all parameters and variables from the parent class, making them available for use in the new methods. If these parameters and methods are not needed, omit the initialization.

To initialize the parent class, add the following line to the __init__ method:

```
super().__init__(model)
```

This call can be placed at the beginning (if parent parameters/variables are required during initialization), in the middle (if needed partway through), or at the end (if not required until later). For most cases, the placement does not significantly affect functionality.

The read_parameters method checks the list of parameters whose values have been updated in the user's text file. It validates these values and updates the corresponding class parameters. This method can also handle special cases where changing one parameter requires updates to other, unrelated parameters. When implementing read_parameters, decide whether to call the parent class version of the method. If the parent's parameters were initialized in __init__, it is generally recommended to read any user updates to those parameters as well.

```
super().read_parameters(model)
```

Similarly, decide whether to call the parent class calculate method. If the parent's parameters were initialized in __init__ and read in read_parameters, it is usually best to calculate values based on those parameters. This makes the parent's calculated results available for use in the subclass.

```
super().Calculate(model)
```

For calculate, the model class is passed in to provide access to not only the logger but also all other classes (e.g., reservoir, surface plant) contained within the model wrapper. Calculations often depend on these related classes. For example, EconomicAddOns might use data from nearly all other classes.

Within the __init__ method, define the parameters for the new class. Use the appropriate parameter constructor for the intended data type: intParameter for integers, floatParameter for floating-point numbers, and other constructors as required. For each parameter, specify the name, value, default value, and valid range (for integer and float types).

Optionally, the user can specify:

- Required (Boolean): Is it required to run? Default value = false.
- ErrMessage (string): What GEOPHIRES will report if the value provided is invalid. Default = "assume default value (see manual)."
- ToolTipText (string): When there is a graphical user interface, this is the text that the user will see. Default = "This is ToolTip Text."
- UnitType (unit type enumeration): The type of units associated with this parameter (e.g., length, temperature, density). Default = Units.NONE.
- CurrentUnits (unit enumeration): What the units are for this parameter (e.g., meters, Celcius, gm/cc). Default = Units:NONE.
- PreferredUnits (units): Usually equal to CurrentUnits, but these are the units that the calculations assume when running. Default = Units.NONE.

The attributes UnitType, CurrentUnits, and PreferredUnits enable GEOPHIRES-X to perform unit and currency conversions. To disable this functionality, omit these attributes. To enable it, refer to the provided code examples for implementation details.

In the __init__ method, determine which local variables will be used, and define their initial values. Also in the __init__ method, define the OutputParameters that will be calculated in the calculate method and made available for use and output in other classes.

Use the OutputParameter constructor for each output parameter. Each output parameter requires a name and value (type any, allowing assignment of, e.g., int, float, bool, list).

The following are optional:

- ToolTipText
- UnitType
- PreferredUnits
- CurrentUnits.

In the __init__ method, note the use of two dictionaries: ParameterDict (stores all input parameters) and OutputParameterDict (stores all output parameters). When a parameter or output parameter is created, it is also added to the corresponding dictionary. These dictionaries are publicly accessible and provide a single reference for all parameters. Follow the convention used in the parent classes when working with these dictionaries.

The ReadParameter() utility function should be used to process all parameters relevant to the object. If certain parameters require additional actions after being modified by the user input, insert the necessary logic here. Refer to the parent classes for examples of how special cases are handled.

In the calculate method, insert the required logic to perform calculations. Available data sources include input parameters, local variables, and all parameters (input and output) from other classes.

Important considerations:

- Calculation order matters. Only use values once they are valid. For example, when extending reservoir, parent output parameters are only valid after the parent calculate method has executed.
- Output values from one class can, in rare cases, be modified by another class's calculate method. The GEOPHIRES-X core code minimizes this, but it is possible.
- Parent input parameters are initialized with default values in the parent __init__ method. These can change during the read_parameters stage for that class, and unrelated parameters could also change due to dependencies. Do not treat input parameters as final until after read_parameters has executed for that class.
- Using self.variable or self.method() affects the local copy within the subclass. If a method is not overridden, calling it with self.method() will still execute the parent version. To directly access or modify the parent variables, parameters, or methods, reference them explicitly through the model object passed into the class and methods. For example, model.reserv is the parent reservoir model, and model.surfaceplant is the parent surface plant model.

Displaying calculation results is typically handled by creating an OutputClass whose primary role is writing results to the output file. In this example, refer to the OutputsAddOns class. Its parent class, outputs, integrates and reports outputs from the base classes. The PrintOutputs method opens the output file (HDR.out) and writes values using formatted text strings.

Values can be written individually or by looping through arrays. It is possible to access and report values from other classes or parent classes, especially if the calculate method modified them. Assume that outputs from other classes were already reported before any modifications made in this class.

For example, the NPV of the project is recalculated in the EconomicAddOns method because this extension modifies the project income, expenses, and profits. The original NPV has already been written to the output file, representing the value before the add-ons. The updated NPV is then reported as part of this class's outputs. This local output parameter, also named NPV, is modified and reported without altering the NPV in the parent economics class.

References

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