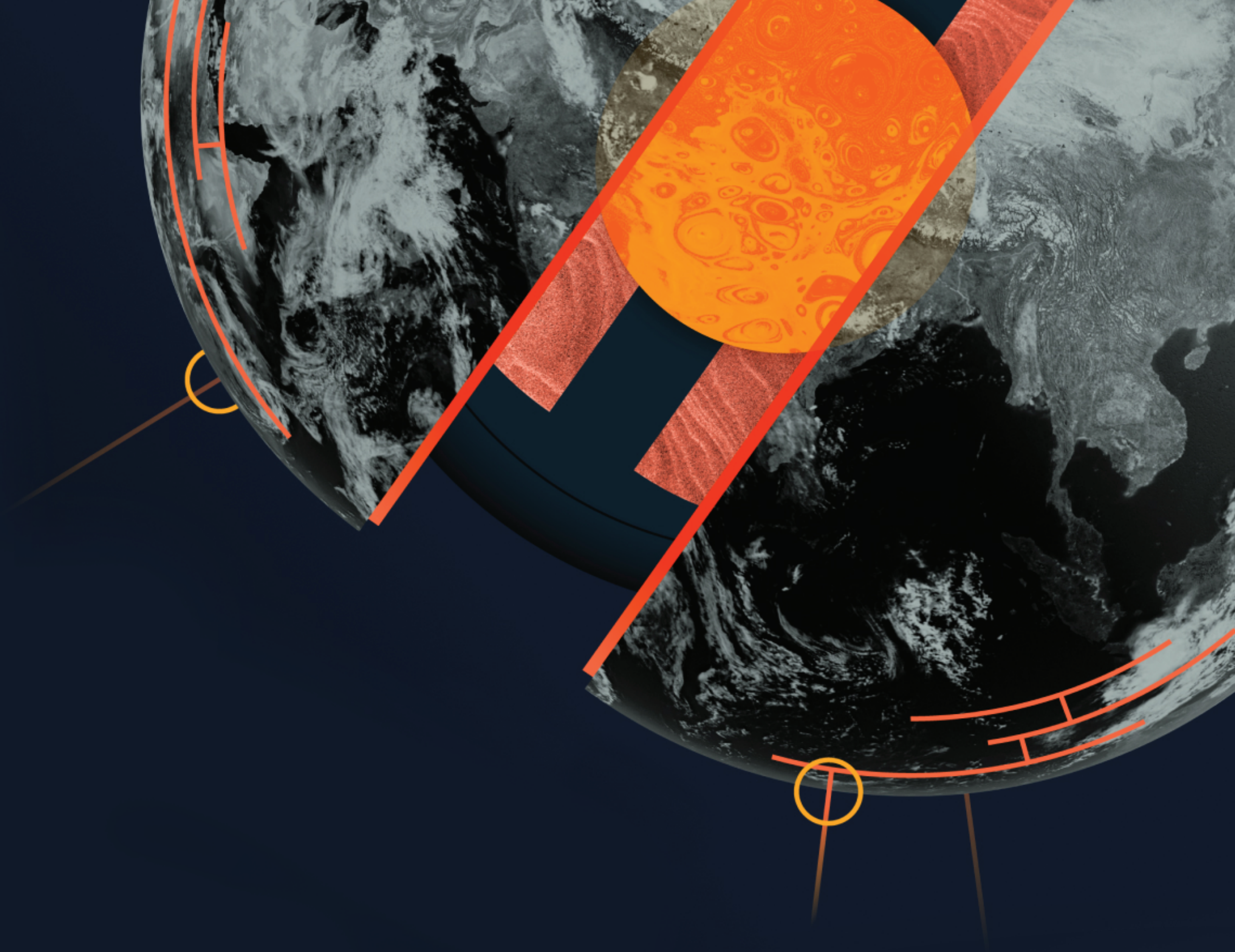

GeoMap™ Beta

User Handbook and Reference Materials
November, 2023

project innerspace™

Contents

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GeoMap™ Overview

The **G**eothermal **E**xploration **O**pportunities Map ("GeoMap™") Beta is being developed by Project InnerSpace, in partnership with Google, to provide essential data and analytics for assessing the development potential for next generation geothermal systems worldwide. The GeoMap™ body of work consists of surface and subsurface modules, a subsurface suitability analysis tool, and a Techno-Economic Sensitivity Tool ("TEST"), all of which work together to provide outputs to user inquiries about geothermal resources and development potential in specific geographies.

The GeoMap™ Beta launch includes as its first case study the continent of Africa, with increasing layer availability as the user zooms in on the country of Nigeria, and the emerging megalopolis of Lagos. This case study approach is intended to illustrate the power and impact of this integrated multi-layer tool. Future iterations of GeoMap™ will increase both the number of data layers in already launched regions, as well as add new regions of the world for exploration and analysis using GeoMap™.

The initial release of GeoMap™ includes some data layers within the United States. This data is being released as part of GeoMap™ Beta because it was utilized in both the creation and in the independent review of the Weighted Overlay Analysis, which is explored in further detail below.

The complete United States dataset, including capabilities similar to those published for Africa, will be published in 2024.

Project InnerSpace prioritizes its mapping efforts on regions of the world that are projected to collectively contain more than 50% of the global population by 2050. We focus on locations where the world's future demand centers will be located. As such, in addition to our first case study of Nigeria, countries such as India, the United States, China, Indonesia, Pakistan, and Brazil are top candidates for near-term inclusion in GeoMap™.

The data inputs informing the surface and subsurface modules of GeoMap™ are derived from the research and development portfolio of Project InnerSpace Phase I. The data is being developed through both internal research and a series of research grants to external scientists and research institutions. For more information about the Project InnerSpace Phase I research and development portfolio, please visit www.projectinnerspace.org.

GeoMap™ is being developed with the goal of enabling broad and robust stakeholder engagement in global geothermal growth and development opportunities, and fills a significant gap in assessing geothermal energy potential by focusing on both subsurface potential and surface suitability, as well as the opportunities geothermal offers for not only power production, but also heating and cooling.

GeoMap™ Beta and any use thereof (including, without limitation, this User Guide and Reference Materials) is subject to the Terms of Service (http://geomap.projectinnerspace.org/termsofservice).

Chapter 1

Surface Module and Electricity Demand

Using the GeoMap™ Surface Module:

The Surface Module is divided into geography and surface themes. Currently, geographies include "Nigeria" and "Global" classifications. The surface module can be used as follows:

Step 1: Select a location of interest on GeoMap™

Begin using the surface module by selecting a location to learn more about. This can be done by either entering the latitude and longitude into the Lat/Long tool on the right-hand side panel, or by clicking directly on a location on the map, panning, and zooming in.

Step 2: Toggle the surface layers

To understand the geology of the selected area and its surface potential, toggle the various GeoMap™ layers on and off. The transparency of each layer can be adjusted, allowing for the stacking of multiple layers for an in-depth view.

Step 3: Learn more about each layer

Users can see additional information for each surface layer by clicking on the icon next to the layer name.

Users can also click on the surface layers directly rendered on the map to query each element's properties. For instance, clicking on a demand raster grid cell for the "Electricity Demand" layer will display the total estimated electricity demand corresponding to that grid cell. Together, these layers provide a multifaceted view of key surface drivers affecting demand for geothermal projects.

How and Why the Surface Module was Constructed:

When exploring for geothermal resources, evaluation of both the surface and the subsurface simultaneously can help to reduce the cost and risk associated with project development.

Identifying and addressing risks and barriers in both these areas is crucial, as they can substantially influence the time and cost involved in progressing through the subsequent phases of geothermal project development.

The GeoMap™ Surface Module assesses surface suitability within the broader context of demand, transmission capacity, risks, data availability, and potential obstacles like protected areas.

As a result of collaboration between Project InnerSpace and partners, including researchers and analysts at MIT, UMass Amherst, and the Energy for Growth Hub, the module contains demand estimates at building-level granularity and at country and continent scales.

The Surface Module augments building footprint data with remote sensing information, and trains machine-learning models utilizing sparse building labels and utility billing data (Lee, 2023). Appendix 1 - Subsurface and Surface Module Data Layers presents a list of all datasets available in GeoMap™, encompassing both Subsurface and Surface Modules. It details the regional coverage of each layer, its name as displayed in GeoMap™, and its relevance to geothermal exploration.

Additionally, the table includes a description of each layer and its corresponding citation.

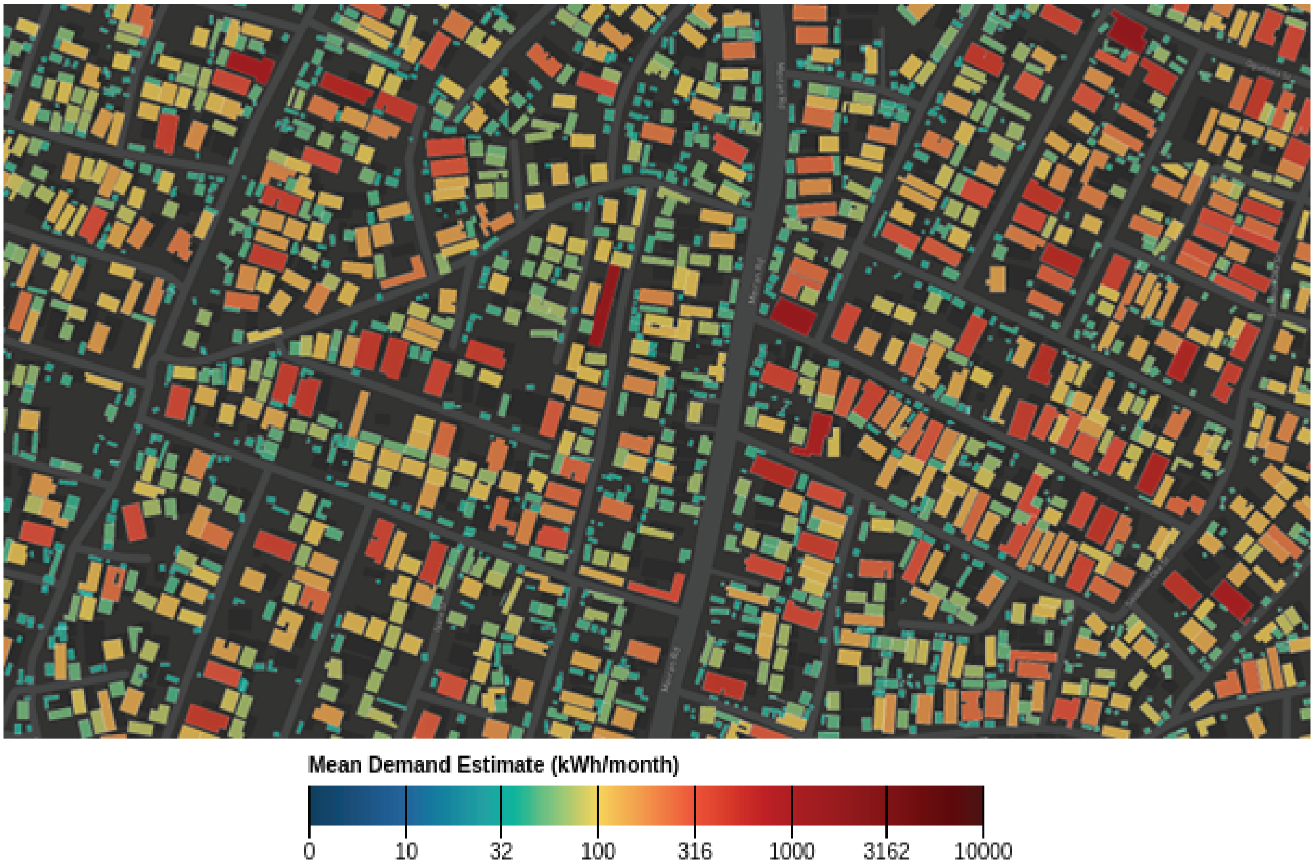

Figure 1.1: Machine learning models trained on metered consumption data estimate electricity demand at the building level in the GeoMap surface module.

Chapter 2

Subsurface Module and Subsurface Favorability Weighted Overlay Analysis

Using the GeoMap™ Subsurface Module:

GeoMap™, designed for both interactivity and educational purposes, features a user interface segmented into geographical modules. These modules are accessible via the data library located on the left-hand side panel. Each geographical area is further divided into four subsurface themes, each vital for assessing geothermal potential:

1) Tectonics

2) Advection

3) Heat Source Proximity

4) Heat Flow

A key accompanies each layer to assist users in interpreting the color schemes represented on the map layers.

Moreover, every layer includes an information button. This button provides the user with essential details, such as the layer's relevance to geothermal resource characterization, a description of the layer, and its associated citation.

Step 1: Select a location of interest on GeoMap™

Begin using the subsurface module by selecting a location to learn more about. This can be done by either entering the latitude and longitude into the Lat/Long tool on the right-hand side panel, or by clicking directly on a location on the map, panning, and zooming in.

Step 2: Toggle the subsurface layers

To understand the geology of the selected area and its geothermal potential, toggle the various GeoMap™ layers on and off. The transparency of each layer can be adjusted, allowing for the stacking of multiple layers for an in-depth view, by clicking on the arrow on the left side of each layer, revealing the opacity slider function.

Step 3: Learn more about each layer by using the query tool

A query tool is available to provide detailed information about each layer. Some layers, such as faults and volcanoes, are more effectively viewed with a specific base map. For example, using the satellite base map helps in visualizing the surface features that correspond to these data layers. There are five different base map options to choose from, and maps can be viewed either as a globe or in a 2D map interface.

Figure 2.1: The interface of the GeoMap™ Beta Subsurface and Surface Modules, by Project InnerSpace 2023

Figure 2.2: The interface of the GeoMap™ Beta Subsurface and Surface Modules, by Project InnerSpace 2023 displaying the Globe format, the key and information (i) tab.

How and Why the Subsurface Module was Constructed:

Tectonic processes and local geology significantly influence local heat flow. The Phase I Subsurface Module is a collection of newly created data from Phase I funded projects, in addition to relevant government and public domain global databases. Project InnerSpace's Phase I research program was designed to promote a multidisciplinary approach to exploring geothermal prospectivity. As a result, the newly created Phase I data incorporates both surface observations such as Cenozoic volcanics, active faulting, and borehole temperature data, as well as modeling aspects that are hidden from view or inaccessible through drilling, such as crustal thickness, and the depth of the lithosphere-asthenosphere boundary. Both observation and modeled datasets are crucial in understanding surface heat flow.

A full list of data layers is available in the Appendix 1 - Subsurface and Surface Module Data Layers below, and are illustrated in the graphic below. Where different models yield similar results of higher heat flow coupled with direct observations, higher confidence was given to the geothermal potential of a region through a weighted overlay analysis approach which is detailed below.

Weighted Overlay Analysis ("Weighted Overlay Analysis" or "WOA") is a Geographic Information System ("GIS")-based technique that enables the combination of different spatial data layers while assigning varying weights based on their relevance and significance for a specific objective. In the context of geothermal exploration, weighted overlay analysis serves to identify and prioritize areas most suitable for geothermal development, considering various geospatial factors like geolo-

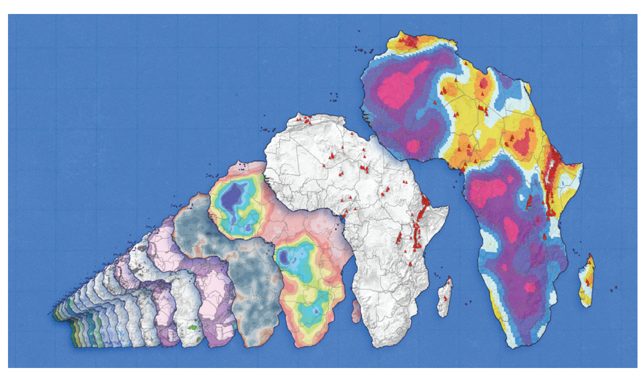

Figure 2.3: The layers included in the surface and subsurface modules, which include outputs from the InnerSpace Phase I research portfolio and publicly avaialble data.

gy, geophysics, temperature, depth, seismic activity, volcanism, and more.

The most appropriate method for assigning class and weight parameters in weighted overlay analysis depends on the availability and quality of data, the criteria and constraints of the analysis, as well as the preferences and expertise of the decision-makers or experts involved. There is no single universally applicable optimal method for all cases.

GeoMap™ includes one subsurface favorability analysis within the beta launch of the tool to be used as a guide. This analysis leverages the subjective judgments of subsurface experts engaged on the Phase I team to assign weights based on their knowledge. In future iterations of GeoMap™, a fully interactive weighted overlay analysis where the user can independently select the weights will be included.

Steps Utilized for Importing and Preparing the Data:

To build the Weighted Overlay Analysis, the required datasets were loaded into Google Earth Engine (GEE). These datasets were then verified to ensure they were in the same projection and had the same spatial resolution as each other to maintain consistency.

Datasets Utilized:

We employed four datasets in the Weighted Overlay Analysis. These datasets represent different criteria relevant to the analysis, and are listed below.

1) Global_Vs_100km_Schaeffer and Lebedev 2013:

a. This dataset represents shear wave speed at 100 km depth according to the global tomographic model SL2013sv. Shear wave tomography at 100 km depth demonstrates a high spatial correlation between negative velocity perturbations and plate boundaries and deformation zones. Nearly 80% of recently active, Quaternary volcanoes lie within microplates and deformation zones.

2) Global_Heatflow_Lucazeau_2019: HFgrid14.csv:

a. Preferred heat flow prediction (Lucazeau 2019) on a 0.5°x0.5° grid and with 14 observables.

3) Active Faults, which included the merged datasets from the following sources. Merging was performed using the Vector tool in QGIS:

a. Global_Active-Faults_GEM
b. Africa_Active_Faults_Project_InnerSpace_2023
c. USA_Great_Basin-Quaternary-Faults_USGS
d. USA_Active_Faults_-AASG-GDS
e. USA_Quaternary_Faults

4) Volcanoes and Vents, which included the merged datasets from the following sources. Merging was performed using the Vector tool in QGIS:

a. Global_Volcanos_HolocenePleistocene_Smithsonian
b. Global_Volcanos_GLB
c. Africa_Igneous_Active_Project_InnerSpace_2023
d. USA_Volcanos_GMNA
e. USA_Hydrothermal_Vents_GMNA
f. USA_Volcanic_Vents_AASG_GDS

Defining the Factor Classes:

We defined factor classes in the Weighted Overlay Analysis in Google Earth Engine by categorizing the input data into classes based on their values. Each class is associated with a specific range of values within the dataset, as shown in the following table.

Inputs			Factor Class					
Used in Global Weighted Overlay Analysis (GeoMap™ Beta)	Unit	Weight % of Total	0	1	2	3	4	5
Proximity to Active/Recent Volcanoes	km	0.19	>10km	10-5	5-3	3-2	2-1	<1
Global_Heat-flow_Luca-	(mW/m2)	0.27	<30	30-80	80-100	100-130	130-180	>180
Proximity to Active/recent faulting	km	0.27	>15km	5-15	5-3	3-2	2-1	<1
Global_Vs_100km_Schaeffer and Lebedev 2013	(mW/m2)	0.27	>4.4189	4.3411-4.4189	4.2633-4.3411	4.1856-4.2633	4.1078-4.1856	<=4.1078

Assigning the Weights:

The weights in the above table were assigned to each of the normalized input factor class datasets, considering their relative significance within the analysis. This step gives higher importance to datasets with higher weights. The multiplication of the raster's was performed in QGIS using the Raster Calculator where each normalized dataset was multiplied by its respective weight to create weighted datasets as defined in Table 1.

The subsurface favorability based on Table 1 was combined with the Slope Angle raster class. ("Subsurface_Favourability@1"*0.9)+("Slope_Merged@1"*0.1)

Rationale: Generally, the most suitable locations for geothermal well pads are almost flat areas (<5%) to very gently sloping areas (6–15%), these values ensure minimal environmental disturbances.

Quality Assurance and Quality Control:

The Weighted Overlay Analysis was independently checked for quality against the following datasets:

1) Global_Active Geothermal Sites_Coro_Trumpy
2) Global_Potential Geothermal Sites_Coro_Trumpy
3) Global_Geothermal_Plants_GEM_Power_Tracker_2023
4) Global_Geothermal_Plants_Below_Threshold_GEM_Power_Tracker_2023
5) USA_Isolated_Geothermal_Systems_USGS
6) USA_Geothermal_Areas_AASG_GDG
7) USA_Identified_Hydrothermal_Sites_USGS

The following six figures provide an overview of output vs. the test dataset.

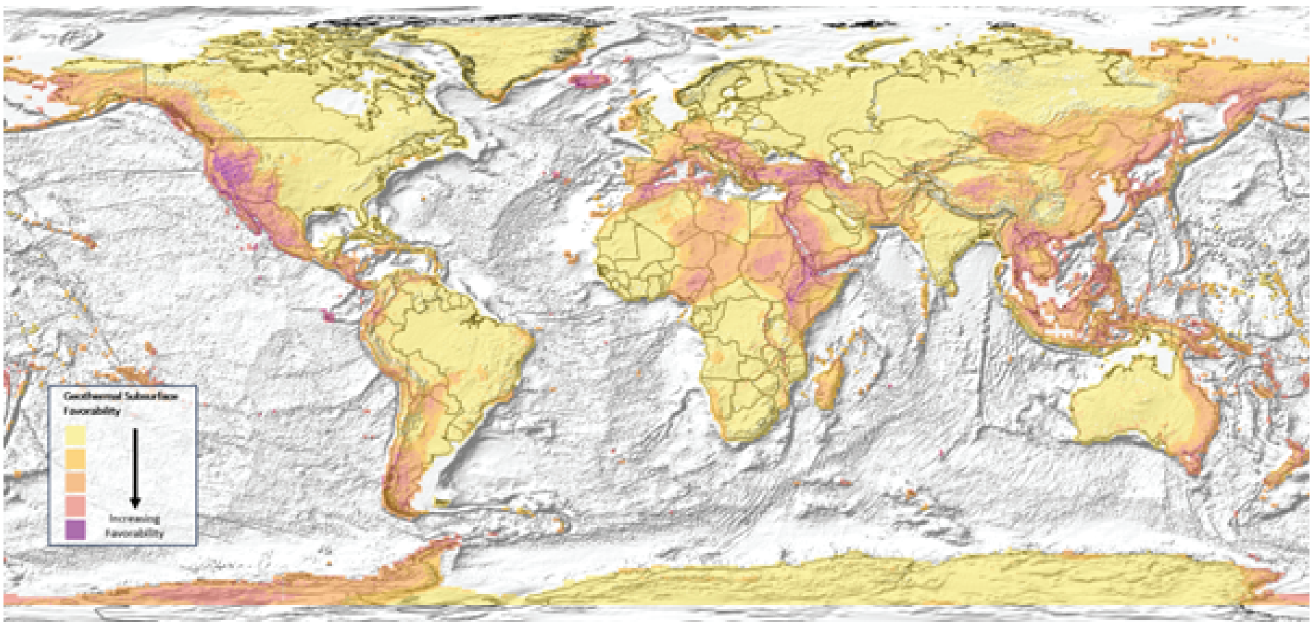

Figure 2.4: Global Geothermal Subsurface Favorability Map by Project InnerSpace 2023

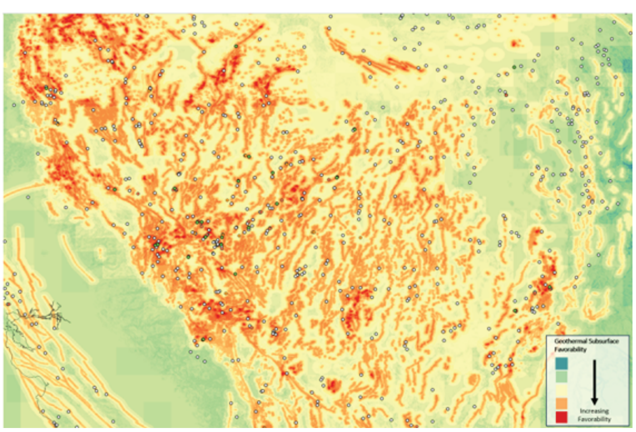

Figure 2.5: Geothermal Subsurface Favorability Map of the Basin and Range area of the Western USA. The dots represent known and potential geothermal sites.

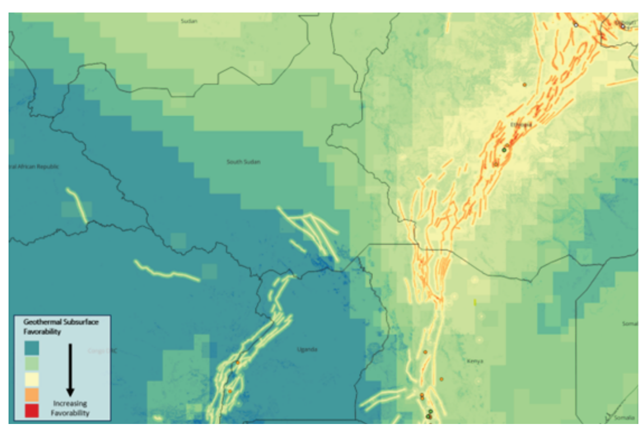

Figure 2.6: Geothermal Subsurface Favorability Map of Eastern Africa. The dots represent known and potential geothermal sites.

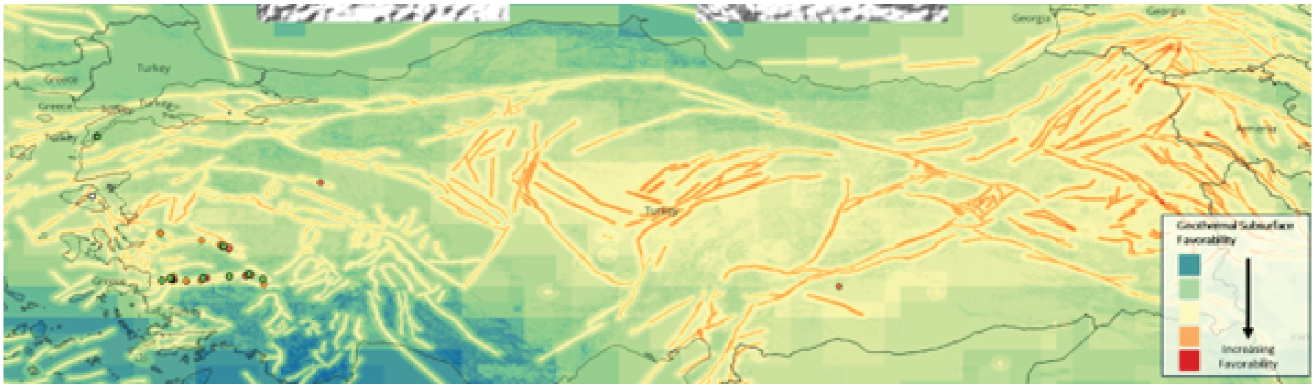

Figure 2.7: Geothermal Subsurface Favorability Map of Turkey. The dots represent known and potential geothermal sites.

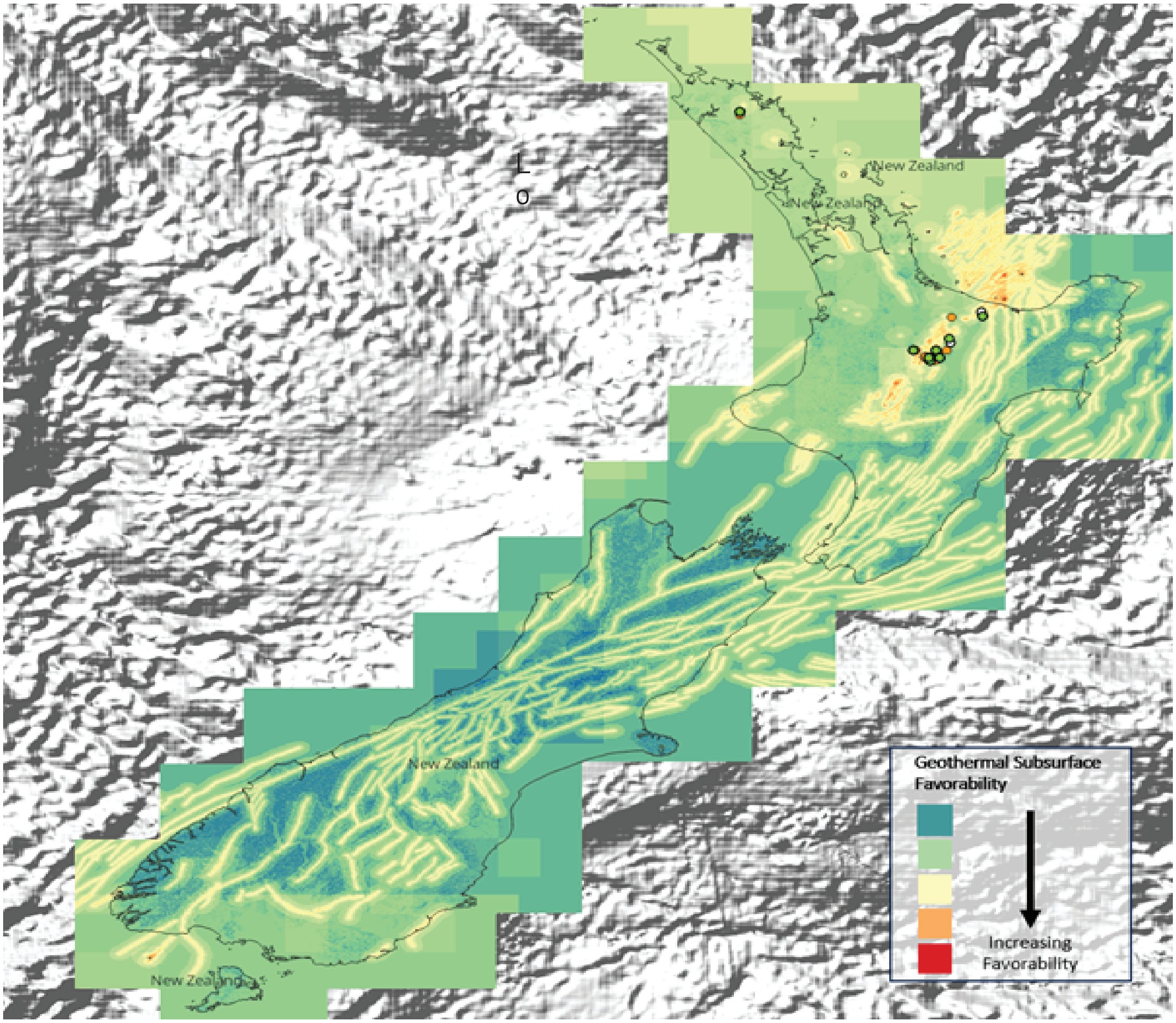

Figure 2.8: Geothermal Subsurface Favorability Map of New Zealand. The dots represent known and potential geothermal sites.

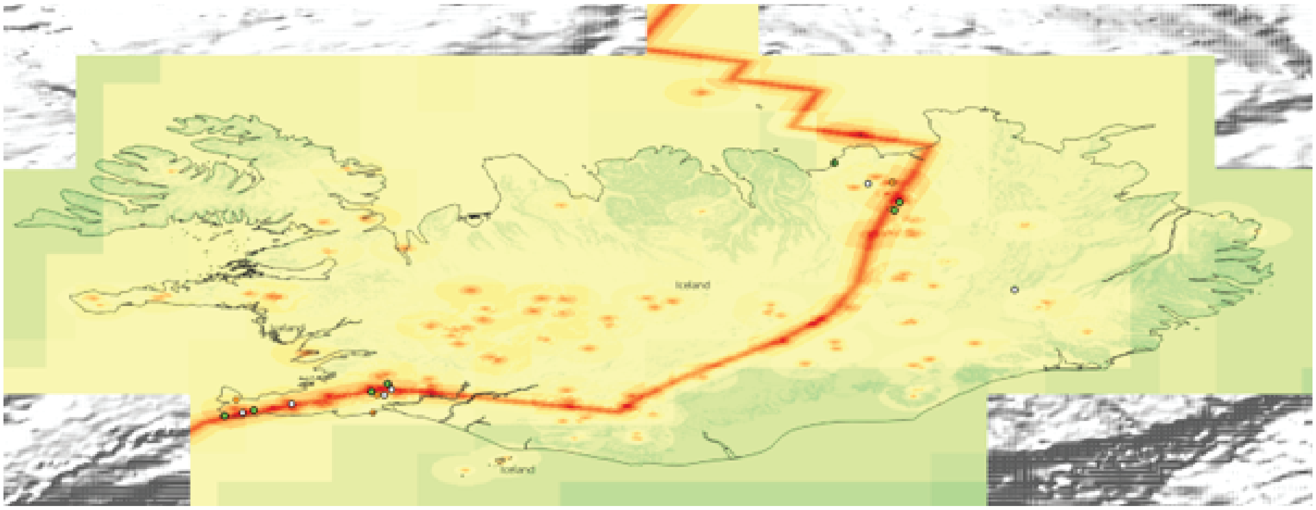

Figure 2.9: Geothermal Subsurface Favorability Map of Iceland. The dots represent known and potential geothermal sites.

GeoMap™ Surface and Subsurface Modules - Approaches and Impact:

The GeoMap™ Subsurface Module is the result of a 'demand pull research' collaboration engaging global experts across various disciplines and institutions, which has been crucial in addressing the broad scope of the required research. For the GeoMap™ Subsurface Module, this included examining the Earth's heat flow by studying the mantle, crust, and sediment layers.

Project InnerSpace's partnership with Google allows for integration of vital global surface datasets. The application of machine learning models to combine various data sources has enabled creation of specific estimates of building-level and continent-scale demand. This unique approach to data creation, integration, and analysis in a freely accessible tool is unprecedented, and designed to make the assessment of geothermal opportunities broadly accessible to all interested stakeholders.

Chapter 3

Techno-Economic Sensitivity Tool ("TEST")

Using the GeoMap™ TEST Module:

TEST is a web-based tool allowing users to click on any potential onshore geothermal project location, sensitize key techno-economic inputs within bounded "sliders" (or accept pre-determined TEST defaults), and export annual project parameters for electric power generation, with summary economic and CO2 reduction measures from any given geothermal project location and input scenarios. In the first quarter of 2024, models focused on direct-use heat energy and direct-use refrigeration/cooling will be released.

TEST is composed of several layers of map derived input data, built-in and user-defined, to generate location-specific project parameters. Map-based subsurface and surface data inform simplified calculations and correlations to estimate the rate of extraction of thermal energy.[1]

Keep in mind that this GeoMap™ Beta launch includes as its first case study the continent of Africa, with increasing layer availability in the surface and subsurface modules as the user zooms in on the country of Nigeria, and the emerging megalopolis of Lagos. This case study approach is intended to illustrate the power and impact of this integrated multi-layer and module tool. **While full layer avaiabliity in the surface and subsurface modules is limited in this Beta launch to the continent of Africa, TEST may be utilized currently anywhere in the world.**

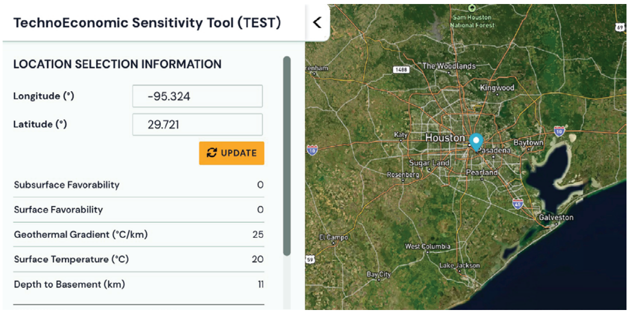

Figure 3.1: TEST retrieves relevant information from the GeoMap subsurface module and the WOA.

Step 1 - Choose your area of interest on the map

Select an onshore location of interest by clicking on the map. The map allows the possibility to zoom in and out and slide back and forth. The map will not yield results if the user selects a location that is offshore.

The top left box will indicate the coordinates of the selected location, and will extract location-specific information for the techno-economic evaluation, including:

- Temperature gradient in the subsurface (in °C/km depth or °F/mile depth), which defines depth to target temperature;
- Depth (in km or miles) to basement (hard) rock; i.e the thickness of the sedimentary rock layers (sandstone, carbonate, shale etc.), which informs well cost estimates. The TEST model

[1] TEST GeoMap™ Beta utilizes water as the working fluid as an underlying assumption. Future iterations of the tool will include models representing engineered working fluids and sCO2.

assumes different drilling costs through basement compared to sedimentary rock, using a default of x2 that the user may vary according to their experience in the target location;

- Assigns summary ranking of 'favorability,' with 1 being low and 5 being highly favorable.

Step 2 - Pick your geothermal energy use case

The user next selects a surface use for geothermal energy. In GeoMap™ TEST Beta, the user may select among three use cases:

- **Electricity generation**
- **Direct use heat; and**
- **Direct use cooling**

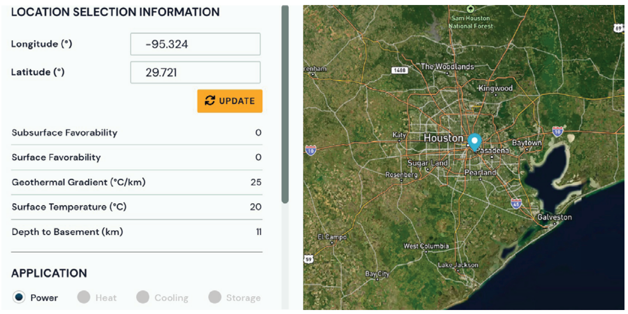

Figure 3.2: TEST allows user to define the application of geothermal energy. GeoMap Beta release only considers Power application in initial release.

Additional use cases will be included in future iterations of the TEST tool. Based on the surface use case selected, specific sliders will appear, prompting the user to define key assumptions for the surface use case.

Step 3 - Choose technical and economic parameters and explore project sensitivities

The user selects the target temperature (production temperature) for any given project application, which works in concert with surface temperature and subsurface gradient data to define well drilling depth.

The subsurface gradient uncertainty slider allows the user to sensitize -20% to 100% (to account for the possible presence of anomalies) of the mapped subsurface gradient and resulting target depth.

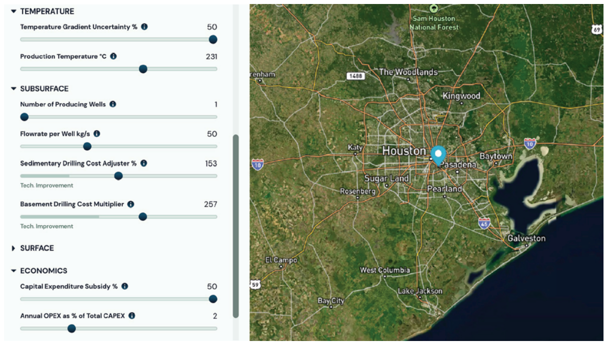

Figure 3.3: TEST sliders allow user to modify the values of relevant variables, within pre-defined ranges.

The user may alter the default water (i.e. "geofluid") flow rate at the surface, which will inform surface use energy output per well.[2] The user may also alter the number of production wells drilled, which will impact project costs and total system output; cost and output variables are available for the user at the bottom of the interface to guide user decision on what flow rates per well and number of wells will be required for a specific energy requirement.

The user may alter the drilling cost, considering as the baseline the current cost in sedimentary basins in oil and gas provinces, and use a slider to explore other values above (to account for region-dependent service market variations) or below the reference value (to enable exploration of technology development scenarios). 1 km of horizontal section is included in all scenarios. Output is provided as 'sedimentary average' cost per drilled foot, a metric that is comparable to current oil and gas operational data. GeoMap™ TEST Beta assumes drilling through the basement will require different unit costs, and thus a separate slider is available to provide a basement drill cost multiplier with respect to the sedimentary average.

The user may also alter the surface facility capital cost as a unit of thermal or electric power output, thus acting in concert with the water flow rate and the production well count to estimate surface facility capital expenditures.

Both the well cost and facility cost sliders are color coded for the purpose of highlighting cost benchmarking. Light green sections describe current state-of-the-art costs, while dark green sections represent levels requiring future technology developments based on the assumptions.

[2] In TEST GeoMap™ Beta, the default is assumed to be 40 kg/s, with an equal ratio of injectors to producers and de minimus system water loss.

Under the power generation surface use selection, the user may alter the assumed turbine thermal conversion efficiency of exergy. To honor thermodynamic constraints and avoid non-realistic pairs of temperature and efficiency, the slider presents a bounded percentage variation over the efficiencies that come from correlations.

Lastly, the user may change a set of variables specific to the economic calculations of the project, including time of construction, magnitude of operating costs, the presence and/or scale of capex subsidies, and a basic discount rate.

Step 4 - TEST provides summary project parameters and economic indicators for any given project scenario

GeoMap™ TEST Beta will produce a series of outputs based on both the GeoMap™ Subsurface Module and user inputs. These outputs are described in the list below.

- **Target Depth:** effective well depth based on surface use target temperature and relevant geographical data.
- **Average Net Electricity Sales:** maximum achieved output based on selected project parameters, minus parasitic pump and surface facility energy consumption.
- **Cost Per Well:** dollar denominated drilling and completion cost per well based on depth and ratio of rock type (sedimentary vs. basement).
- **Average Drilling Cost:** dollar denominated drilling cost per length unit (meter or foot) on a total measured depth basis (i.e. vertical plus horizontal drilling length) across both sedimentary and basement well segments.
- **Surface Facility Cost:** dollar denominated capital expenditures for surface use-specific facilities. Note these costs do not include infrastructure beyond surface facility scope.
- **Simple Pre-Tax Payout Price:** calculates a pre-tax, real, levelized price per unit of net energy output (i.e. MWh electric, Thermal BTU or cooling ton) for 25 year life of project energy output to match discounted cash inflows and outflows based on the user's inputs.[3]
- **Lifetime Project Generation:** represents the aggregate of energy generated annually over the life of the project.
- **Foregone CO2 Emissions vs Nat. Gas:** estimates the amount of foregone CO2 emissions with respect to gas, over the life of the project.
- **Surface Footprint:** estimates land requirements for the geothermal plant and wells.

OUTPUT	
Target Depth (km)	9.2
Average Net Energy Sales (MWe)	5.2
Cost per Well (mm$)	22.7
Average Drilling Cost ($/m)	1882
Surface Facility Cost (mm$)	12.3
Simple Pre-Tax Payout Price ($/Mwh-e)	59.21
Lifetime Project Generation (GWh-e)	1087.2
Foregone CO2 Emissions vs gas (mm ton CO2)	1061.1
Surface Footprint (ha)	2.0

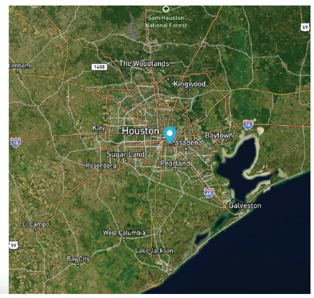

Figure 3.4: Results are displayed, and vary automatically as the user changes any of the input variables.

Underlying Calculations and Assumptions in TEST:

GeoMap™ Beta and the associated **T**echno-**E**conomic **S**ensitivity **T**ool ("TEST") are being developed to provide essential data and analytics for assessing scalable geothermal systems worldwide.

The goal is to maximize the usability of GeoMap™ information beyond the expertise of subsurface specialists, and translate the available datasets in technical and financial variables to catalyze informed policy decisions, provide supporting data to enable capital investments, and foster awareness of the geothermal potential in regions currently off the radar.

Each of the descriptions below are addressed further in Appendix 2 below, and are also available in GeoMap™ TEST Beta by clicking the information icon next to each variable.

[3] Simple Payout Price may be comparable to some formulations of Levelized Cost of Energy (LCOE, LCOH or LCOC) but given the wide variety of underlying assumptions and methodologies we have chosen to use a more precise description of our calculation. TEST allows for detailed export of annual cash flows and key project parameters to allow users to overlay any specific approach relating to inflation factors, capital structure, tax regimes, performance factors etc....

Inputs Derived from the GeoMap™ Subsurface Module

Surface temperature: or SBIO1 is the Annual Mean Temperature of soil for the selected location. Soil temperature layer was calculated by adding monthly soil temperature offsets to monthly air-temperature maps from CHELSA (date range 1979-2013) (Karger et al. 2017). These soil temperature layers were then used to calculate annual means, temperature ranges, standard deviation, warmest and coldest months and quarters for Soil Bioclim Layers between 0-5 cm and 5-15 cm depth. For details of the methodology please refer to Lembrechts et al. (2021). For all surface use cases, soil temperature and ambient temperature are assumed to be equal.

Geothermal Gradient: The global geothermal gradient map was created by Project Innerspace utilizing the HFgrid14.csv: preferred heat flow prediction (Lucazeau 2019) on a 0.5ºx0.5º grid and with 14 observables and combining it with a range of thermal conductivities for cratons and sedimentary basins. A refined geothermal gradient map is being generated by Project InnerSpace and will replace this dataset upon completion.

Depth to basement: Global continental sedimentary thickness, where estimates in Africa and Arabia are from Holdt and White (in prep) and estimates outside of these regions using sediment thickness data from the CRUST 1.0 model (Laske et al., 2013) for continental regions. A new sedimentary thickness map is being generated by Project InnerSpace and will replace this dataset upon completion.

Favorability Subsurface and Favorability Surface: The subsurface and surface favorability indices are the results of the Weighted Overlay Analysis (Weighted Overlay Analysis) from the Global Mapping project. Please refer to the documentation inside that Module.

TEMPERATURE

Production Temperature: This is the water temperature at point of entry to surface facilities, accounting for losses in the well and surface network; the lower bound constraint is 80°C because the GeoMap™ Beta Tool focuses on deep geothermal targets, rather than shallow heat pump applications. The upper bound is constrained to 320°C, as there is not sufficient technical data to support operational performance in excess of 320°C.

Temperature Gradient Uncertainty: The user may modify the temperature gradient coming from maps with an uncertainty range between plus 100% and minus 20%.

- **Surface Temperature Losses:** fixed at 4°C to conservatively account for transport losses.
- **Well Temperature Losses:** GeoMap™ Beta version does not undertake reservoir simulations to relate flow rate to pressure and/or temperature.[4] To simplify, GeoMap™ Beta sets the bottom hole temperature of the fluid produced to be equal to the temperature of the bulk reservoir resource. To evaluate the well bore losses with time due to the decline in inlet bottom hole temperature with time, we apply a calculation based on Ramey's Wellbore heat transmission model (Ramey 1962) to estimate the Geofluid temperature drop in the production well.
  - Ramey's model calculates the Geofluid temperature drop in the production wells, called well losses (°C), using the following equation:
  - Well Losses=

$$(T_{r,0} - T_w) - \omega(L - \Gamma) + (T_w - \omega\Gamma - T_{r,0})exp\left(\frac{L}{\Gamma}\right)$$

- with $T_{r,0}$ as the initial rock temperature at the bottom of the well (°C), T_W as the Geofluid
- temperature at the bottom of the well (°C), ω as the average geothermal gradient (°C m⁻¹), and L as the depth of the reservoir (m), equal to the length of the well assuming vertical wells. As a simplification, reservoir and interaction between injector and producer is not considered, and hence $T_{r,0}$ is equivalent to $T_{w,0}$.
- The parameter Γ (m) is calculated assuming that the thermal resistances of the casing and cement are negligible compared with the rock:

$$\Gamma = \frac{m_{prod} c_W f(t)}{2\pi k_r}$$

- with m_{prod} as the Geofluid flowrate (kg s^{-1}) and f(t) as the time function for a line heat source given by:

$$f(t) = -\,ln\left(\frac{d_{cas}}{4\sqrt{\alpha_r t}}\right) - 0.29$$

[4] As GeoMap™ is expanded to provide deep dives around selected regions, later versions of this tool will consider location specific reservoir characteristics such as permeability and porosity, and different technologies for extraction of heat, as described in the Roadmap..

- In this time function equation, dcas is the outer diameter of the casing (m). The time t is the cumulative time that the well has been producing, i.e., by accounting for the utilization factor. Ramey's model assumes the Geofluid is an incompressible, single phase liquid with constant specific heat capacity.

- As explained above, the workflow uses the target temperature to determine the depth of the resource to be harvested, accounting for temperature losses in the surface network and in the production well; Ramey's equation needs to have a depth to determine the temperature losses in the well, leading to the need to iterate and solve depth and temperature losses. The well length and the well temperature loss values are initialized as follows:

○ Well Losses (t=0) = 10°C

○Tw,i = Tprod + Surface losses + Well losses (t=0)

○ Li = (Tw,i – Tamb)/ω

- Where Tw,i is the initial temperature of the resource rock, equivalent to the Bottom hole Temperature of the geofluid in our case, ω as the average geothermal gradient (°C m^{-1}), Tamb, the ambient air temperature (°C). These initial values are used to calculate the Ramey functions, f(t) and parameter Γ, to estimate the temperature losses in the well after 1 year. From this initial estimate of well losses, the tool calculates a revised bottom hole Temperature and L.

○Thermal Decline: Fixed at 0.5% based on existing hydrothermal plants [Mines, 2016] and we assume a linear thermal decline in the bottom hole temperature with time.

$$T_{w,1} = T_{w,0} * (1-p)$$

- T_w is the Bottom Hole Temperature in°C, p the annual decline in temperature each year, i is the timestep in years. p is set to 0.5% in this GeoMap ™ Beta version. Future versions will include decline curves that are commonly considered for specific downhole designs and more consistent with EGS / AGS developments (i.e. hyperbolic, lognormal or exponential).

SUBSURFACE

Flowrate per well: Bounded conditions of 25 to 100 kg/s per production well based on observed production tests and minimum viable technical levels.

- **Fluid Type:** GeoMap™ Beta version is based on the use of water to harvest geothermal energy. Correlations are used for water properties, coming from IAWPS data (2018). Future versions will allow for the use of other fluids.

Number of Producing Wells: One injection well is assumed for each production well in this version.

- **Well length:** Vertical section is defined by target depth, with an assumed horizontal length of 1km.

- **Well Diameter:** Above 60 kg/s flow rate per well, the external diameter is set to 9 5/8 inch, and below 60 kg/s, to 7 inch. The same diameter is used for the injector and the producer wells. Flow rate is fixed for life of project and thus diameter only impacts wellbore temperature losses, and friction losses to calculate the parasitic loads for pumping.

- **Productivity / Injectivity Indices:** Both the productivity index and the injectivity index are assumed to be a fixed 5 kg/s-bar, which only influences parasitic load given fixed flow rates.

- **Pump Requirements:** Pump power requirements are calculated annually over the life of the project to capture the impact of declining reservoir temperature. The frictional pressure drop in each well (Pwell,fr) is calculated using the Darcy-Weisbach equation:

$$P_{well,fr} = f \rho_{w,well} \frac{v^2}{2} \frac{L}{d_{well}}$$

  - ○ f is the friction factor (–),
  - ○ ρ w,well is the temperature-averaged density of the water (kg m^{-3}),
  - ○ v is the average water velocity in the well (m s^{-1}), d_{well} is the wellbore diameter (m).
  - ○ Friction factor is obtained from Colebrook-White equation:

$$\frac{1}{\sqrt{f}} = -2log_{10}\left(\frac{\frac{e}{d_{well}}}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

  - ○ e is the tubing surface roughness (default set to 0.0001 m)
  - ○ Re is the Reynolds Number for flow in the wellbore.

- The hydrostatic pressure $P_{well,hydro}$ (Pa) is calculated as follows:

$$P_{well,hydro} = \rho_{w,wel}\, g\, L$$

- g is the gravitational acceleration (9.81 m s–2)
- L is the length of the well

Sedimentary Drilling Cost Adjuster[5] : GeoMap Beta separates drill cost estimation between sedimentary rock and basement rock. The estimation of drilling cost in the sedimentary rock segment uses a simplified cost as a function of depth approach, without accounting for specific rock properties. Users are allowed to modify the drilling cost per foot as a percentage of the reference value. Beta relies on current oil and gas unconventional drilling data from operators in the deep, high-temperature Haynesville Shale (SWN, 2023, CHK, 2022 and CRK, 2023) to define a reference drill cost per measured foot at 300 $/ft. That metric is then increased by an assumed 25% to transform 5 inch oil and gas well diameters to an assumed 7 inch geothermal well diameter to yield a reference drilling cost of 375 $/ft.

Drilling cost bounds are defined as a multiplier of the reference drilling cost; the sliders bounds are defined in a range between 1000 $/ft (267% increase) and 150 $/ft (40% decrease with respect to baseline): the former is the high end of the historic geothermal drilling cost data showed in Frash, 2023 and the latter is consistent with a potential technology development equivalent to other renewable resources, and consistent with "ATB" advanced scenario (NREL, 2023) and "Earthshot" scenario in the USA (Augustine, 2023). Note that no exploration costs, pilot hole costs or other 'pre-drill' costs are assumed in the GeoMap™ Beta methodology.

Basement Drilling Cost Multiplier: The GeoMap™ Beta relies on a simplified approach for estimating basement drilling cost as a multiple of the calculated sedimentary drilling cost per foot given a relative paucity of basement drilling cost data relative to sedimentary targets. The user can select a multiple between 1x to 4x which is multiplied by the calculated sedimentary drill cost per foot, as described above, with an initial value at 2. This cost factor is multiplied by the basement drilling length, and horizontal segment, as defined by the depth to target temperature and depth to basement data, to calculate the basement drilling cost. Note that the basement drill cost methodology also does not account for specific rock properties in the basement.

SURFACE

Power Generation Use Module

Power Plant Efficiency Increase over baseline: Heat-to-power conversion is simplified as a direct function of production temperature, using efficiency correlations of existing power cycles from Beckers (2019). To consider technology improvements that may enhance the conversion efficiency of heat into power as a function of temperature, the user can vary turbine conversion efficiency over a preset baseline. This approach that modifies the efficiency relative to a baseline is meant to reduce incoherent scenarios relative to production temperature, but still provide for the potential contribution of next generation technology (e.g. supercritical CO_2 turbines), with slider bounds defined as 0 - 25%. The GeoMap™ Beta does not automatically adjust user defined capital costs at higher conversion efficiencies.

Power Plant Costs: GeoMap™ Beta applies a simplified approach to determine the cost of surface facilities, by applying a formula of $/kW that does not consider the size of the plant in the cost of the facilities. Power Plant cost bounds are defined in a range between 1000 $/kW and 4000 $/kW.

Key baseline parameters include:

- **Power Plant efficiency:** This is derived from the work of Beckers (2019), where a number of simulations with different refrigerants were run to define a curve for utilization efficiency as a function of temperature. In this work, we utilize sub-critical ORC up to 190°C and double flash at higher temperatures.

- **Ambient Temperature:** The surface temperature coming from the Global Mapping tool is used as the ambient temperature to account for the fact that the efficiency decreases as the ambient temperature of the ambient increases.

- **Net power:** Gross power minus parasitic loads from production / injection systems including 2% assigned to air-cooler losses.

[5] Note that all well costs assume a fixed 1km horizontal section for heat harvesting stimulation with a fixed assumption of $3.5 mm completion cost per well that is changed by either of the drill cost sliders. The GeoMap™ Beta does not change the stimulation cost budget for basement versus sedimentary targets due to a lack of technical and cost data.

Heat Use Module (Release Date: First Quarter, 2024)

Surface Heat Exchanger Costs: allows the user to adjust the capital cost per unit of heat capacity ($/kWth) to account for varying levels of surface heat exchange infrastructure and end use facility integration. GeoMap™ Beta assumes a default amount of $100/kWth based on Beckers (2017). Slider bounds are defined as 50-150 $/kWth.

Capacity Factor: allows the user to define the amount of output from the geothermal installation relative to nameplate capacity. Most industrial process contracts require base load heat supply (>90%), but some installations or heat use scenarios may operate at lower levels of efficiency or require higher levels of reserve capacity.

Import Cost of Electricity: asks the user to input estimated local power prices for any given project location. Heat-only projects will need to purchase power to run well pumps as the project will not generate power for consumption. Reference value is set at 0.07 $ / kWhe. The local power price is multiplied by annual required pump power to calculate a power purchase cost of output sold.

Cooling Use Module (Release Date: First Quarter, 2024)

In addition to the Heat Use Module assumptions described above, the cooling module also includes:

Absorption Chiller Cost: allows the user to adjust the capital cost per unit of cooling output in refrigeration tons ($/ton) to account for various heat to cooling conversion equipment.

GeoMap™ Beta assumes a default amount of 2000 $/ton based on DOE (2017). Slider bounds are defined as 1800-6000 $/ton based on DOE (2017).

Absorption Chiller Coefficient of Performance ('COP'): allows the user to adjust the ratio of electrical power consumed relative to cooling output. This allows the user to consider future performance efficiency improvements and in concert with the wholesale power rate will define power purchase costs for the project.

GeoMap™ Beta assumes a default amount of 0.8 based on DOE (2017). Slider bounds are defined as 0.7-1.4 based on DOE (2017).

ECONOMICS

Capital Expenditure Subsidy: Users can apply a percentage of CAPEX subsidy to explore what incentive policies may achieve in terms of assuring the viability of geothermal projects. In the GeoMap™ Beta the capex subsidy amount equals a cash payout at the commencement of production and does not consider specific regulatory regimes of project location.

Annual OPEX as % of Total CAPEX: Annual operating and maintenance costs are calculated as a percentage of total capital cost. The User may modify the default 2% value.

Wells and Plant Construction Time: Users may modify the time to build the wells and plants. The GeoMap™ Beta assumes the project is 'shovel-ready' and does not consider exploration or permitting time in its calculations.

Discount rate: Users may modify the discount rate; the default is zero.

OUTPUT

Target Depth: Once the user selects a production temperature, TEST computes the necessary depth to achieve the target temperature. This calculation takes into consideration the temperature gradient, surface temperature at the chosen location, and temperature losses incurred during flow from the reservoir to the process inlet.

Average Net Energy Sales: yields the available power for sale, after subtracting parasitic losses from both the pumping system and air cooler losses (in power application).

Cost Per Well: calculates the cost of the well by accounting for both sedimentary and basement drilling lengths, vertical and horizontal sections, and the cost per unit length coming from the sliders of Sedimentary Drilling Cost Adjuster and Basement Drilling Cost Multiplier.

Average Drilling Cost: It yields the average cost per unit length in the production and injection wells, including both the sedimentary and basement sections.

Surface Facility Cost: calculates the cost of surface facilities (Flash/Rankine, heat exchanger or absorption chiller) by multiplying the Plant Cost ($/kWe or $/kWth) by the installed capacity.

Simple Pre-tax Payout Price (output): calculates a pretax, real, levelized price per unit of output (i.e. MWh electric, Thermal BTU or cooling ton) for the production life to match discounted cash inflows and outflows based on the user's inputs.

Lifetime Project Generation: represents the aggregate of energy generated annually over the life of the project.

Foregone Emissions vs Gas: estimates the amount of foregone CO2 emissions (mm tons) over the life of the project. The calculator for the power generation module assumes displacement of a natural gas CCGT baseload plant which the EIA estimates has an emissions intensity of 976 lb / MWh in the United States (EIA, 2021). The calculators for heating use 396 lb/Mwth based on [EPA, 2020].

Surface Footprint: estimates land requirements for geothermal wells and plan using as reference the data published by Lovering et al (2022), with a median value of 45 ha/TWhy per unit of electricity production.

GeoMap™ TEST Beta - Approach and Impact:

The initial GeoMap™ TEST Beta release is designed for simplicity and ease of use, but with a level of rigor that ensures meaningful outputs; complexities that might act as a barrier of entry for certain audiences have been removed, to ensure accessibility for a broader audience, making it accessible even to those without a specialist background.

TEST GeoMap™ Beta, in its initial launch, includes analyses relevant to the techno-economics of open-loop systems with production / injection doublet wells, to support scalable solutions such as Blind Geothermal, Engineered Geothermal Systems, and Next Generation Engineered Geothermal Systems as described by Beard (2023). Future iterations of TEST will include analyses of Advanced Geothermal Systems/Closed Loop Systems and Hybrid Geothermal Systems, as well as modules focused on subsurface energy storage, regional geothermal penetration models, and non-water working fluids.[6]

Future Iterations and Development Roadmap

GeoMap™ TEST Beta is intended to complement the GeoMap™ Surface and Subsurface Modules, and allow for a translation of the subsurface and surface favorability maps into economic viability. GeoMap™ Beta will allow users to have an initial understanding of the potential for geothermal deployment worldwide, but it is considered a starting point to develop a more comprehensive tool over the next months and provide a deeper analysis of geothermal potential on local, country and regional bases.

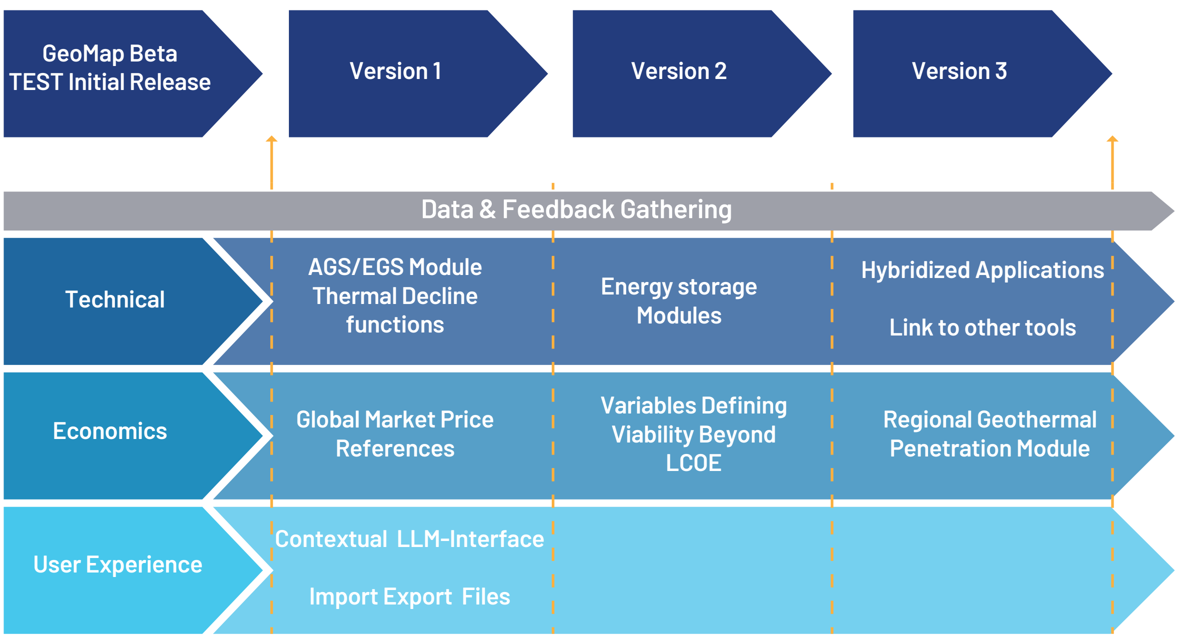

Figure 3.5: Graphical representation of planned iterations and future capabilities of GeoMap™

[6] TEST does not evaluate shallow closed loops coupled with heat pumps for residential purposes.

GeoMap™ Beta will include in future iterations the following add-on capabilities and analyses, which will be rolled out over the next 18-24 months in conjunction with future Surface and Subsurface Module publications. Feedback from users will assist in prioritization of additional capabilities as the tool evolves.

Contextual LLM-Interface: User experience will be enhanced by the implementation of an intuitive interface with generative-AI, to integrate LLM and facilitate the usability of the tool beyond the modification of sliders in the current interface.

AGS/EGS Module + Thermal decline functions: GeoMap™ Beta considers a constant thermal decline, and the temperature at the surface shows a linear decreasing relationship with production time. By adding new temperature decline functions to the user (e.g. log, exp, plateau followed by sharp decrease), a better representation of novel technologies like EGS/AGS will be achieved, to show the extended potential of geothermal in zones that are initially not seen as favorable, This function will include considerations such as the utilization of non-aqueous working fluids, like sCO2.

Energy Storage Module: GeoMap™ Beta is focused on illustrating the potential of geothermal as a baseload energy source. The possibilities that geothermal brings in terms of power or thermal energy storage will be developed in additional modules.

Hybridization Module: Models that combine geothermal applications (power, heat, cooling and / or storage) and integration with other renewables are more resilient and optimized and will be treated in a specific module.

Global Market Price References: GeoMap™ Beta does not enter into the comparison of geothermal economics with other resources; future versions will work on providing comparisons of geothermal costs with other renewable sources and explore penetration potential in regional markets, where other energy resources may have limitations.

Variables Beyond LCOE: Geothermal is a capital intensive resource, which leads to LCOE values that are typically higher than other renewable energy resources, but it is superior in terms of baseload availability, low surface footprint and lower geopolitical exposure in the supply chain than other renewables and indeed some fossil fuels. GeoMap™ Beta already provides several metrics beyond LCOE to highlight the opportunities that geothermal gives, but new versions will provide a more comprehensive comparative analysis of multiple parameters.

Regional Geothermal Penetration Module: GeoMap™ Beta provides single-point economics, but further work will be carried out to be able to analyze regions and explore the degree of penetration of geothermal resources.

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Appendix 1 - Subsurface and Surface Module Data Layers

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Subsurface Favorability	Africa	Advection	Africa_Thermal_Springs_Mac-Geology	Thermal springs are surface manifestations of geothermal activity. When hot water or steam from the Earth's interior reaches the surface, it creates these springs. Their presence serves as a visible and easily identifiable indicator of the underlying geothermal reservoir.	Based largely on data from thermal springs of the United States and other countries of the world; a summary (usgs.gov) and from the Algerian Renewable Energy Atlas (2019). The dataset represents hyperthermal hot springs (more than 70°C) and steaming ground.	Macgregor, D. D., 2020. Regional variations in geothermal gradient and heat flow across the African plate. Journal of African Earth Sciences, Volume 171, 2020, 103950, ISSN 1464-343X, https://doi.org/10.1016/j.jafrearsci.2020.103950.
Subsurface Favorability	Africa	Advection	Africa_Igneous_Active_Project_InnerSpace_2023	Surface occurrence of igneous rocks are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction.	The igneous activity database includes the spatial distribution of active and inactive igneous rocks, including intrusions and extrusions.	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophysics, Geosystems, https://doi.org/10.1029/2021GC009897.
Subsurface Favorability	Africa	Heat Flow	Africa_Calculated_Surface_Heatflow__Project_InnerSpace_2023	Surface heat flow is a direct indicator of the thermal energy emanating from the Earth's interior. Regions with high surface heat flow often indicate a greater potential for geothermal resources.	Predicted steady-state surface heat flow based on WINTERC_Africa_InnerSpace lithospheric model for an average continental crustal radiogenic heat production of 0.9 microW/m3.	Fullea, J. and Clemente-Gomez, C. 2023 an update for the African Continent based on the previous work of Fullea, J., Lebedev, S., Martinec, Z., & Celli, N. L. (2021). WINTERC-G: mapping the upper mantle thermochemical heterogeneity from coupled geophysical-petrological inversion of seismic waveforms, heat flow, surface elevation and gravity satellite data. Geophysical Journal International, 226(1), 146-191.
Subsurface Favorability	Africa	Heat Source Proximity	Africa_Sedimentary_Thickness_Project_InnerSpace_2023	The depth of sedimentary thickness is a crucial factor in geothermal exploration. It serves as a key indicator for determining drill depth before reaching the crystalline basement, and this information has a	Sediment thickness, primarily based on seismic and well data.	Holdt, M and White, N. (in prep). Global Sedimentary Thickness Constraints.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
				significant impact on both project economics and the choice of extraction techniques. The total heat flux at the Earth's surface can be broken down into three major components: mantle heat flux, crustal heat flux, and sediment heat flux. Sediment heat flux accounts for the heat transfer from the Earth's mantle and crust through the overlying sedimentary layers to the surface. The thickness of these sedimentary layers influences the heat transfer process, as thicker sediments can act as insulators and affect the rate at which heat is conducted to the surface.		
Subsurface Favorability	Africa	Heat Source Proximity	Africa_Sedimentary_Thickness_Project_datalocation_InnerSpace_2023	The depth of sedimentary thickness is a crucial factor in geothermal exploration. It serves as a key indicator for determining drill depth before reaching the crystalline basement, and this information has a significant impact on both project economics and the choice of extraction techniques. The total heat flux at the Earth's surface can be broken down into three major components: mantle heat flux, crustal heat flux, and sediment heat flux. Sediment heat flux accounts for the heat transfer from the Earth's mantle and crust through the overlying sedimentary layers to the surface. The thickness of these sedimentary layers influences the heat transfer process, as thicker sediments can act as insulators and affect the rate at which heat is conducted to the surface.	Location of data used to generate sedimentary thickness.	Holdt, M and White, N. (in prep). Global Sedimentary Thickness Constraints.
Subsurface Favorability	Africa	Heat Source Proximity	Africa_Vs_110km_AF2019	The high spatial correlation between negative velocity perturbations and plate boundaries and deformation zones revealed by shear wave tomography is significant for geothermal exploration. Plate boundaries and deformation zones often serve as conduits for heat transport,	Shear wave speed at 110 km depth in Africa extracted from AF2019, a regional 3D shear wave velocity model for Africa.	Celli, N.L., Lebedev, S., Schaeffer, A.J. et al. African cratonic lithosphere carved by mantle plumes. Nat Commun 11, 92 (2020). https://doi.org/10.1038/s41467-019-13871-2.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
				which can enhance geothermal potential. Identifying these areas is critical for locating geothermal resources. The observation that nearly 80% of recently active Quaternary volcanoes lie within microplates and deformation zones highlights the connection between geothermal activity and tectonic features. Shear wave tomography can assist in pinpointing the locations of these tectonic features beyond the surface expression of active volcanoes. The map highlights S-wave velocity deviations (δ Vs) from the regional average (4.38 km/s) at 110 km depths Higher Vs (dark blue, purple) indicates colder, thicker lithosphere.		
Subsurface Favorability	Africa	Heat Source Proximity	Africa_Moho_Depth_Project_InnerSpace_2023	The depth of the Moho is an indicator of the thickness of the Earth's crust. Thicker crusts generally result in more heat production due to the presence of radioactive isotopes (U, K and Th) in the Earth's crust. As a result, the heat flow from the Earth's interior to the surface is influenced by the thickness of the crust. The amount of decay depends strongly on geology, but in areas of thick crust it may contribute more than 50% of total heat flux at the surface. The Moho depth also plays a role in the conductive heat transfer from the Earth's interior to the surface. The deeper the Moho, the longer the path for heat to travel from the mantle to the crust. Conventional geothermal fields demonstrate a shallowing of the Moho (Hermant et al., 2019).	WINTERC-G_Africa_InnerSpace: Depth to the crust-mantle boundary (Moho discontinuity) from joint integrated geophysical-petrological inversion of surface wave fundamental mode dispersion data, surface elevation and heat flow. Crustal thickness= surface elevation+Moho depth.	Fullea, J. and Clemente-Gomez, C. 2023 an update for the African Continent based on the previous work of Fullea, J., Lebedev, S., Martinec, Z., & Celli, N. L. (2021). WINTERC-G: mapping the upper mantle thermochemical heterogeneity from coupled geophysical-petrological inversion of seismic waveforms, heat flow, surface elevation and gravity satellite data. Geophysical Journal International, 226(1), 146-191.
Subsurface Favorability	Africa	Heat Source Proximity	Africa_Lithosphere_Thickness_Project_InnerSpace_2023	The total heat flux at the Earth's surface is a sum of various components, including heat flux from the mantle, crust, and sediment layers. The mantle's contribu-	WINTERC-G_Africa_InnerSpace: Depth to the Lithosphere-Asthenosphere Boundary (LAB) from joint	Fullea, J. and Clemente-Gomez, C. 2023 an update for the African Continent based on the previous work of Fullea, J., Lebedev, S.,

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				tion to heat flux is inversely proportional to lithospheric thickness. A thinner lithosphere corresponds to a higher mantle heat flux (e.g. ~40 mW/m2 for 100 km lithosphere, 20 mW/m2 for 200 km lithosphere). This relationship is essential for estimating the potential heat available at different depths and locations, which directly impacts geothermal resource assessment. The Lithosphere is thickest in old stable cratons estimated to be between 200 and 250 km and shallowest at newly formed oceanic crust. Conventional geothermal fields demonstrate a thin lithosphere (Hermant et al., 2019).	integrated geophysical-petrological inversion of surface wave fundamental mode dispersion data, surface elevation and heat flow.	Martinec, Z., & Celli, N. L. (2021). WINTERC-G: mapping the upper mantle thermochemical heterogeneity from coupled geophysical-petrological inversion of seismic waveforms, heat flow, surface elevation and gravity satellite data. Geophysical Journal International, 226(1), 146-191.
Subsurface Favorability	Africa	Tectonics	Africa_Igneous_-Facies_Project_Inner-Space_2023	Surface occurrence of igneous rocks are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction.	The Igneous Activity Database includes the spatial distribution of active and inactive igneous rocks, including intrusions and extrusions.	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophysics, Geosystems, https://doi.org/10.1029/2021GC009897.
Subsurface Favorability	Africa	Tectonics	Africa_-Faults_Crustal_Scale_Project_InnerSpace_2023	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones,	Within the Structural Elements Database we include an indication of the depth affected by each feature. For example, whether it cuts into the basement rocks, or is restricted to the surface stratigraphy.	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophysics, Geosystems, https://doi.org/10.1029/2021GC009897.

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				transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.		
Subsurface Favorability	Africa	Tectonics	Africa_-Faults_Basement_Penetration_Project_InnerSpace_2023	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	Within the Structural Elements Database we include an indication of the depth affected by each feature. For example, whether it cuts into the basement rocks, or is restricted to the surface stratigraphy.	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophysics, Geosystems, https://doi.org/10.1029/2021GC009897
Subsurface Favorability	Africa	Tectonics	Africa_-Faults_Cuts_Stratigraphy_Project_InnerSpace 2023	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	Within the Structural Elements Database we include an indication of the depth affected by each feature. For example, whether it cuts into the basement rocks, or is restricted to the surface stratigraphy.	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophysics, Geosystems, https://doi.org/10.1029/2021GC009897

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Subsurface Favorability	Africa	Tectonics	Africa_Faults_Sh-alow penetra-tion_Project_In-nerSpace 2023	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	Within the Structural Elements Database we include an indication of the depth affected by each feature. For example, whether it cuts into the basement rocks, or is restricted to the surface stratigraphy.	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophys-ics, Geosystems, https://-doi.org/10.1029/2021GC009897
Subsurface Favorability	Africa	Tectonics	Africa_-Faults_Stress_Pro ject_Inner-Space_2023	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	The Structural Elements Database includes the latest kinematics of each fault (compressional, extensional, strike-slip), where this is known or can be interpreted	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophys-ics, Geosystems, https://-doi.org/10.1029/2021GC009897.
Subsurface Favorability	Africa	Tectonics	Africa_Faults_Pro-ject_Inner-Space_2023	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may	The Structural Elements Database includes the surface and sub-surface trace of each feature.	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
				provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.		Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophysics, Geosystems, https://doi.org/10.1029/2021GC009897.
Subsurface Favorability	Africa	Tectonics	Africa_Sedimentary_Basins_Mac-Geology	Sedimentary Basins are caused by extension (rifting) that thins the lithosphere, increasing the heat from the mantle. The heat generated by these geological processes can persist for a considerable period after rifting has occurred. Understanding the time since rifting helps assess the availability and sustainability of the heat source for geothermal energy production. The formation age of each of these basins is included in the metadata. In addition different sedimentary basins can have varying thermal conductivities, which affect the ability of rocks to transfer heat.	Detailed Sedimentary Basins of Africa digitized from multiple data sources and publications, both academic (onshore) and industry sourced (mainly offshore).	Macgregor, D.D., 2020. Regional variations in geothermal gradient and heat flow across the African plate. Journal of African Earth Sciences, Volume 171, 2020, 103950, ISSN 1464-343X, https://doi.org/10.1016/j.jafrearsci.2020.103950.
Subsurface Favorability	Africa	Tectonics	Africa_Active_-Faults_Project_InnerSpace_2023	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	The activity of each fault in the Structural Elements Database is recorded, where this can be observed directly (drainage offsets, recent fault scarps, seismicity), or assumed active through spatial proximity to recent seismicity.	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophysics, Geosystems, https://doi.org/10.1029/2021GC009897.

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Subsurface Favorability	Africa	Tectonics	Africa_Crustal_Facies_Project_InnerSpace_2023	Different crustal facies have varying thermal conductivities, which influence the ability of the Earth's crust to conduct heat. Understanding the thermal properties of crustal facies is critical for assessing the subsurface's heat transfer capabilities. Facies with high thermal conductivity can facilitate the transfer of heat from deeper geological layers to shallower depths, potentially enhancing geothermal potential. In addition Crustal facies can vary in their radiogenic heat production. Some facies may contain higher concentrations of radioactive elements, which generate heat through radioactive decay. These heat-producing facies can contribute to higher subsurface temperatures and potentially increase the geothermal potential of an area.	The Crustal Facies Database records the large-scale composition and thickness of crustal blocks at the present-day	Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2023 an update for the African Continent based on the previous work of Markwick, P.J., Paton, D.A. and Mortimer, E.J. 2021. Reclus: A new database for investigating the tectonics of the Earth: the East African margin and hinterland. Geochemistry, Geophysics, Geosystems, https://doi.org/10.1029/2021GC009897.
Subsurface Favorability	Global	Advection	Global_Thermal_Springs_Tamburello_et_al.,2022	Thermal springs are surface manifestations of geothermal activity. When hot water or steam from the Earth's interior reaches the surface, it creates these springs. Their presence serves as a visible and easily identifiable indicator of the underlying geothermal reservoir.	Dataset digitized format of the thermal springs of the world compiled by Gerald Ashley Waring in 1965. The data set contains geographical coordinates (from georeferentiation), temperatures, flow rates and other data. The information has been complemented with different recent geological data sets available in the literature.	Tamburello, G., Chiodini, G., Ciotoli, G. et al. Global thermal spring distribution and relationship to endogenous and exogenous factors. Nat Commun 13, 6378 (2022). https://doi.org/10.1038/s41467-022-34115-w
Subsurface Favorability	Global	Advection	Global_Volcanos_Holocene-Pleistocene_Smithsonian	Volcanoes are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction. Volcanic regions tend to have higher geothermal temperatures due to the nearby magma chambers. These elevated temperatures can result in superheated geothermal fluids and steam, which are ideal for generating electricity efficiently.	GVP_Holocene+Pleistocene.shp - Smithsonian Global Volcanic Program, lists of known volcanic centers from the Holocene and Pleistocene; Completed review of 2022 eruptions. Current eruptions updated through 9 June 2023. General updates to volcano data. New episode type option added for submarine activity.	Global Volcanism Program, 2023. [Database] Volcanoes of the World (v. 5.1.3; 13 Oct 2023). Distributed by Smithsonian Institution, compiled by Venzke,E: https://doi.org/10.5479/si.GVP.VOTW5-2023.5.1

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Subsurface Favorability	Global	Advection	Global_Volca-nos_GLB	Volcanoes are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction. Volcanic regions tend to have higher geothermal temperatures due to the nearby magma chambers. These elevated temperatures can result in superheated geothermal fluids and steam, which are ideal for generating electricity efficiently.	This datalayer is point coverage containing basic geographic and geologic information for worldwide volcanoes thought to have been active in the last 10,000 years (Holocene). The data is a collection of informa-tion by Smithsonian Institution volcanologists summarizing 1,509 volcanoes and this version of the data set was published as part of the USGS Global GIS : global coverage database. The data was adapted from Simkin and Siebert, 1994 "Volcanoes of the World: an Illustrated Catalog of Holocene Volcanoes and their Eruptions" and produced digitally by the Smithsonian Institution's Global Volcanism Program. Volcanoes are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction.	Smithsonian Institution. Global Volcanism Program. American Geological Institute. Geological Survey (U.S.). Environmental Systems Research Institute (Redlands, Calif.). (2003). Global GIS : volcanoes of the world ; volcano basic data. [Shapefile]. American Geological Institute. Retrieved from https://earthworks.stanford.edu/-catalog/harvard-glb-volc.
Subsurface Favorability	Global	Advection	Global_HotSpots	Hotspots are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction.	A global plate model was used to reconstruct the locations of large igneous provinces relative to plumes and mid-ocean ridges at the time they formed. Advection describes the transport of heat by a moving fluid or a rock mass. Examples include hydrothermal circulation in porous rocks. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction. Volcanos, Vents, thermal springs and recent Large Igneous Provinces (LIPS) are all signs of advection.	Yoshida M. and M. Santosh, Energet-ics of the Solid Earth: An integrated perspective, Energy Geoscience, 1, 28-35, doi:10.1016/j.en-geos.2020.04.001, 2020. https://y-oshida-geophys.jp/-data_hotspot.htm. I

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Subsurface Favorability	Global	Advection	Global_Large_Igneous_Provinces_Johansson-etal-2018	LIPS are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction.	Large Igneous Provinces (LIPs) are intraplate magmatic events, involving volumes of mainly mafic magma upwards of 100 000 km3, and often above 1 million km3. Throughout Earth's history, such mega-volcanic events have occurred in both continental and oceanic environments, and are typically characterized by a short duration magmatic pulse or pulses (less than 1–5 million years). LIPS are a form of Advection, the transport of heat by a moving fluid or a rock mass. Examples include hydrothermal circulation in porous rocks. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction.	Johansson, L., Zahirovic, S., & Müller, R. D. (2018). The interplay between the eruption and weathering of Large Igneous Provinces and the deep-time carbon cycle. Geophysical Research Letters, 45, 5380 –5389. 6. 10.1029/2017GL076691.
Subsurface Favorability	Global	Advection	Global_Active Geothermal Sites_Coro_Trumpy	Known Geothermal Sites.	IGA - Global Geothermal Energy Database	G. Coro and Trumpy, E., 2020. Predicting geographical suitability of geothermal power plants. Journal of Cleaner Production 267 (2020) 121874
Subsurface Favorability	Global	Advection	Global_Potential Geothermal Sites_Coro_Trumpy	Potential Geothermal Sites.	IGA - Global Geothermal Energy Database	G. Coro and Trumpy, E., 2020. Predicting geographical suitability of geothermal power plants. Journal of Cleaner Production 267 (2020) 121875
Subsurface Favorability	Global	Advection	Global_Geothermal_Power_Tracker_July_2023	Known Geothermal Sites.	The Global Geothermal Power Tracker (GGtPT) is a worldwide dataset of geothermal power facilities. A geothermal power plant can be composed of several units, or just a single unit. Units can consist of multiple turbines, constructed at different times and several units may make up one geothermal power station. The GGtPT includes geothermal power plant units with capacities of 30 megawatts (MW) or more, and catalogs every geothermal	Global Energy Monitor, Global Geothermal Power Tracker, July 2023 Release.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
					power plant unit at this capacity threshold of any status, including operating, announced, pre-construction, under construction, shelved, canceled, mothballed, or retired. Various types of geothermal plant technologies are tracked in the dataset, including flash steam, dry steam, binary cycle, and others. Each geothermal plant included in the tracker is linked to a wiki page on the GEM wiki. The most recent release of this data was in July 2023.	
Subsurface Favorability	Global	Advection	Global_Geothermal_Plants_Below_Threshold_GEM_Power_Tracker_2023	Potential Geothermal Sites.	The Global Geothermal Power Tracker (GGtPT) is a worldwide dataset of geothermal power facilities. A geothermal power plant can be composed of several units, or just a single unit. Units can consist of multiple turbines, constructed at different times and several units may make up one geothermal power station. The GGtPT includes geothermal power plant units with capacities of 30 megawatts (MW) or more, and catalogs every geothermal power plant unit at this capacity threshold of any status, including operating, announced, pre-construction, under construction, shelved, canceled, mothballed, or retired. Various types of geothermal plant technologies are tracked in the dataset, including flash steam, dry steam, binary cycle, and others. Each geothermal plant included in the tracker is linked to a wiki page on the GEM wiki. The most	Global Energy Monitor, Global Geothermal Power Tracker, July 2023 Release.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
					recent release of this data was in July 2023.	
Subsurface Favorability	Global	Heat Flow	Global_Heat-flow_Luca-zeau_2019	Surface heat flow is a direct indicator of the thermal energy emanating from the Earth's interior. Regions with high surface heat flow often indicate a greater potential for geothermal resources.	HFgrid14.csv: preferred heat flow prediction (Lucazeau 2019) on a 0.5°x0.5° grid and with 14 observables.	Lucazeau, F. (2019). Analysis and mapping of an updated terrestrial heat flow data set. Geochemistry, Geophysics, Geosystems, 20, 4001–4024. https://-doi.org/10.1029/2019GC008389.
Subsurface Favorability	Global	Heat Flow	Global_SBIO1_An-nual_Mean_Soil_-Tempera-ture_5_15cm	This layer is required in order to hang the Geothermal Gradient from to get a depth to a certain temperature.	SBIO1 = Annual Mean Tempera-ture. Soil temperature layers were calculated by adding monthly soil temperature offsets to monthly air-temperature maps from CHELSA (date range 1979-2013) (Karger et al. 2017, Sci Data). These soil temperature layers were then used to calculate annual means, temperature ranges, standard deviation, warmest and coldest months and quarters for Soil Bioclim Layers between 0-5 cm and 5-15cm.	Johan van den Hoogen, Jonas Lembrechts, SoilTemp, Ivan Nijs, & Jonathan Lenoir. (2021). Global Soil Bioclimatic variables at 30 arc second resolution (Version 1) https://doi.org/10.5281/zeno-do.4558732.
Subsurface Favorability	Global	Heat Flow	Global_IHFC_-data_Africa_up-date_Project_In-nerSpace_2023	Surface heat flow is a direct indicator of the thermal energy emanating from the Earth's interior. Regions with high surface heat flow often indicate a greater potential for geothermal resources.	Compilation of global heat-flow data by the International Heat Flow Commission (IHFC; www.ihfc-iugg.org) of the International Association of Seismology and Physics of the Earth's Interior (IASPEI). The presented data update contains data generated between 1939 and 2023 and constitutes the first intermediate update benefiting from the global collaborative assessment and quality control of the Global Heat Flow Database running since May 2021 http://assess-ment.ihfc-iugg.org/.	Global Heat Flow Data Assessment Group; Fuchs, Sven; Neumann, Florian; Norden, Ben; Beardsmore, Graeme; Chiozzi, Paolo; Colgan, William; Anguiano Dominguez, Ana Paulina; Duque, Maria Rosa Alves; Ojeda Espinoza, Orlando Miguel; Forster, Florian; Förster, Andrea; Fröhder, Robert; Fuentes, Karina; Hajto, Marek; Harris, Robert; Jõeleht, Argo; Liebing, Helena; Liu, Shaowen; Lüdtke, Gwendolin; Madon, Mazlan; Negrete-Aranda, Raquel; Poort, Jeffrey; Reznik, Itay J.; Riedel, Michael; Rolandone, Frédérique; Stål, Tobias; Verdoya, Massimo; Wu, Jyun-Nai (2023): The Global Heat Flow Database: Update 2023. V. 1. GFZ Data Services. https://doi.org/10.5880/fid-geo.2023.008.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Subsurface Favorability	Global	Heat Flow	Global_Geother-mal_Gradient	The geothermal gradient is the rate at which temperature increases with depth in the Earth's crust. It serves as a direct indicator of the subsurface temperature conditions. A higher geothermal gradient indicates a more rapid increase in temperature with depth.	The global geothermal gradient map was created by Project Innerspace utilizing the HFgrid14.csv: preferred heat flow prediction (Lucazeau 2019) on a 0.5°x0.5° grid and with 14 observables and combining it with a range of thermal conduc-tivities for cratons and sedimen-tary basins.	Project InnerSpace 2023 based on the work of (Lucazeau 2019)
Subsurface Favorability	Global	Heat Source Proximity	Global_Litho-sphere_Thick-ness_WINTERC-G	The total heat flux at the Earth's surface is a sum of various components, including heat flux from the mantle, crust, and sediment layers. The mantle's contribu-tion to heat flux is inversely proportional to lithospheric thickness. A thinner lithosphere corresponds to a higher mantle heat flux (e.g. ~40 mW/m2 for 100 km lithosphere, 20 mW/m2 for 200 km lithosphere). This relationship is essential for estimating the potential heat available at different depths and locations, which directly impacts geothermal resource assessment. The Lithosphere is thickest in old stable cratons estimated to be between 200 and 250 km and shallowest at newly formed oceanic crust. Conven-tional geothermal fields demonstrate a thin lithosphere (Hermant et al., 2019)	Depth to the Lithosphere Asthenosphere Boundary (LAB) from joint integrated geophysi-cal-petrological inversion of surface wave fundamental mode dispersion data, surface elevation and heat flow. The LAB is deepest in old stable cratons estimated to be between 200 and 250 km and shallowest at newly formed oceanic crust. Conventional geothermal fields demonstrate a rising of the LAB.	Fullea, J., Lebedev, S., Martinec, Z., & Celli, N. L. (2021). WINTERC-G: mapping the upper mantle thermo-chemical heterogeneity from coupled geophysical-petrological inversion of seismic waveforms, heat flow, surface elevation and gravity satellite data. Geophysical Journal International, 226 (1), 146-191.
Subsurface Favorability	Global	Heat Source Proximity	Global_Mo-ho_Depth_WIN-TERC-G	The depth of the Moho is an indicator of the thickness of the Earth's crust. Thicker crusts generally result in more heat production due to the presence of radioactive isotopes (U, K and Th) in the Earth's crust. As a result, the heat flow from the Earth's interior to the surface is influenced by the thickness of the crust. The amount of decay depends strongly on geology, but in areas of thick crust it may contribute more than 50% of total heat flux at the surface. The Moho depth also plays a role in the conductive heat transfer from the Earth's interior to the	Global_Moho_WINTERC-G.xyz: crust-mantle discontinuity depth (km, >0 downwards).	Fullea, J., Lebedev, S., Martinec, Z., & Celli, N. L. (2021). WINTERC-G: mapping the upper mantle thermo-chemical heterogeneity from coupled geophysical-petrological inversion of seismic waveforms, heat flow, surface elevation and gravity satellite data. Geophysical Journal International, 226 (1), 146-191.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
				surface. The deeper the Moho, the longer the path for heat to travel from the mantle to the crust. Conventional geothermal fields demonstrate a shallowing of the Moho (Hermant et al., 2019)		
Subsurface Favorability	Global	Heat Source Proximity	Global_Sedimentary_Thickness	The depth of sedimentary thickness is a crucial factor in geothermal exploration. It serves as a key indicator for determining drill depth before reaching the crystalline basement, and this information has a significant impact on both project economics and the choice of extraction techniques. The total heat flux at the Earth's surface can be broken down into three major components: mantle heat flux, crustal heat flux, and sediment heat flux. Sediment heat flux accounts for the heat transfer from the Earth's mantle and crust through the overlying sedimentary layers to the surface. The thickness of these sedimentary layers influences the heat transfer process, as thicker sediments can act as insulators and affect the rate at which heat is conducted to the surface.	Global continental sedimentary thickness, where estimates in Africa and Arabia are from Holdt and White (in prep) and estimates outside of these regions use sediment thickness data from the CRUST 1.0 model (Laske et al., 2013). https://igp-pweb.ucsd.edu/~gabi/crust1.html.	Global continental sedimentary thickness, where estimates in Africa and Arabia are from Holdt and White (in prep) and estimates outside of these regions are from Laske et al., 2013. https://igp-pweb.ucsd.edu/~gabi/crust1.html.
Subsurface Favorability	Global	Heat Source Proximity	Global_Basement_Thickness_-Stephenson et al., 2023	Thicker crusts generally result in more heat production due to the presence of radioactive isotopes (U, K and Th) in the Earth's crust. As a result, the heat flow from the Earth's interior to the surface is influenced by the thickness of the crust. The amount of decay depends strongly on geology, but in areas of thick crust it may contribute more than 50% of total heat flux at the surface. Continental collision zones with stacked upper crustal nappes and, hence, thicker radiogenic heat producing layers, can cause long-lived positive thermal anomalies.	Measurements of crustal thickness based on passive and active source seismic experiments.	Stephenson, S. N., Hoggard, M. J., Holdt, M. C. and White, N.J. (in review). Continental Residual Topography Extracted from Global Analysis of Crustal Structure
Subsurface Favorability	Global	Heat Source Proximity	Global_Basement_Thick-	Thicker crusts generally result in more heat production due to the presence of	Crustal thickness, interpolated from the measurements of	Stephenson, S. N., Hoggard, M. J., Holdt, M. C. and White, N.J. (in

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
			ness_grid_Inner-Space_2023	radioactive isotopes (U, K and Th) in the Earth's crust. As a result, the heat flow from the Earth's interior to the surface is influenced by the thickness of the crust. The amount of decay depends strongly on geology, but in areas of thick crust it may contribute more than 50% of total heat flux at the surface. Continental collision zones with stacked upper crustal nappes and, hence, thicker radiogenic heat producing layers, can cause long-lived positive thermal anomalies.	Stephenson et al., (in review); CRUST 1.0 is used in locations where measurements are absent.	review). Continental Residual Topography Extracted from Global Analysis of Crustal Structure
Subsurface Favorability	Global	Heat Source Proximity	Global_Vs_100km_ Schaeffer and Lebedev 2013	The high spatial correlation between negative velocity perturbations and plate boundaries and deformation zones revealed by shear wave tomography is significant for geothermal exploration. Plate boundaries and deformation zones often serve as conduits for heat transport, which can enhance geothermal potential. Identifying these areas is critical for locating geothermal resources. The observation that nearly 80% of recently active Quaternary volcanoes lie within microplates and deformation zones highlights the connection between geothermal activity and tectonic features. Shear wave tomography can assist in pinpointing the locations of these tectonic features beyond the surface expression of active volcanoes. The map highlights S-wave velocity deviations (δ Vs) from the regional average (4.38 km/s) at 110 km depths Higher Vs (dark blue, purple) indicates colder, thicker lithosphere.	Shear wave speed at 100 km depth according to the global tomographic model SL2013sv. Shear wave tomography at 100 km depth demonstrates a high spatial correlation between negative velocity perturbations and plate boundaries and deformation zones. Nearly 80% of recently active, Quaternary volcanoes lie within microplates and deformation zones.	Schaeffer, A.J. and S. Lebedev. Global shear speed structure of the upper mantle and the transition zone. Geophysical Journal Interna-tional, 194, pg 417-449, 2013. doi:10.1093/gji/ggt095.
Subsurface Favorability	Global	Tectonics	Global-Earth-quakes_eq-m5.5_ NEIC	Earthquakes typically occur around unstable areas such as plate boundaries or collision zones and are therefore common in geothermal regions. However, while their presence may indicate geothermal potential, they can also cause problems in executing a geothermal project.	NEIC earthquake catalog, magnitude 5.5+ from 1990 to 2020. ANSS, 2020. Comprehen-sive Earthquake Catalog (ComCat)	NEIC earthquake catalog, magnitude 5.5+ from 1990 to 2020. ANSS, 2020. Comprehensive Earthquake Catalog (ComCat)

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Subsurface Favorability	Global	Tectonics	Global_Earth-quakes_eq-m3-5.5_NEIC	Earthquakes typically occur around unstable areas such as plate boundaries or collision zones and are therefore common in geothermal regions. However, while their presence may indicate geothermal potential, they can also cause problems in executing a geothermal project.	NEIC earthquake catalog, magnitude 3-5.5 from 1990 to 2020. ANSS, 2020. Comprehensive Earthquake Catalog (ComCat)	NEIC earthquake catalog, magnitude 3-5.5 from 1990 to 2020. ANSS, 2020. Comprehensive Earthquake Catalog (ComCat)
Subsurface Favorability	Global	Tectonics	Global_Active-Faults_GEM	An understanding of fault patterns, depth of penetration and stress type is important when exploring geothermal systems. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	The GEM Foundation's Global Active Faults project (GEM-GAF) is building a comprehensive, global dataset of active fault traces of seismogenic concern. The dataset comprises GIS files hosted here of fault traces and a small amount of relevant attributes or metadata (fault geometry, kinematics, slip rate, etc.) useful for seismic hazard modeling and other tectonic applications. The dataset is being assembled primarily as a part of GEM's global Probabilistic Seismic Hazard Modeling efforts, although we hope that the data find wide use in research, education and general interest among many users.	Styron, Richard, and Marco Pagani. "The GEM Global Active Faults Database." Earthquake Spectra, vol. 36, no. 1_suppl, Oct. 2020, pp. 160–180, doi:10.1177/8755293020944182.
Subsurface Favorability	Global	Tectonics	Global_Plate-Boundaries_Hasterok	The geological processes at plate boundaries, such as subduction zones and rift zones, can lead to elevated subsurface temperatures.	Active tectonic plates and their boundary zones	Hasterok, D., Halpin, J., Hand, M., Collins, A., Kreemer, C., Gard, M.G., Glorie, S., (revised) New maps of global geologic provinces and tectonic plates, Earth Science Reviews. Preprint available (EarthArXiv). https://doi.org/10.31223/X5TD1C.
Subsurface Favorability	Global	Tectonics	Global_Geological_Province_Hasterok	This layer provides a very high-level overview of Crustal Facies. Different crustal facies have varying thermal conductivities, which influence the ability of the Earth's crust to conduct heat. Understanding the thermal properties of crustal facies is critical for assessing the subsurface's heat transfer capabilities. Facies with high thermal conductivity can	Geological provinces, their type and last orogenic event.	Hasterok, D., Halpin, J., Hand, M., Collins, A., Kreemer, C., Gard, M.G., Glorie, S., (revised) New maps of global geologic provinces and tectonic plates, Earth Science Reviews. Preprint available (EarthArXiv) https://doi.org/10.31223/X5TD1C.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
				facilitate the transfer of heat from deeper geological layers to shallower depths, potentially enhancing geothermal potential. In addition Crustal facies can vary in their radiogenic heat production. Some facies may contain higher concentrations of radioactive elements, which generate heat through radioactive decay. These heat-producing facies can contribute to higher subsurface temperatures and potentially increase the geothermal potential of an area.		
Subsurface Favorability	Global	Tectonics	Global_Cratons_Hasterok	The Lithosphere is thickest in old stable cratons estimated to be between 200 and 250 km. The mantle's contribution to heat flux is inversely proportional to lithospheric thickness, therefore old cratonic areas tend to be cold.	Regions with geochemical samples or that are known to have Archean (>2500 Ma) basement. The polygons have largely been extracted from global_gprv.shp aside from a few in the western US from Lund et al. (2015, https://doi.org/10.3133%2Fds898. An additional column in the attribute table has been added to identify post-Archean reworking.	Hasterok, D., Halpin, J., Hand, M., Collins, A., Kreemer, C., Gard, M.G., Glorie, S., (revised) New maps of global geologic provinces and tectonic plates, Earth Science Reviews. Preprint available (EarthArXiv) https://doi.org/10.31223/X5TD1C.
Subsurface Favorability	Global	Tectonics	Global_Seismic_Hazard_GEM	Earthquakes typically occur around unstable areas such as plate boundaries or collision zones and are therefore common in geothermal regions. However, while their presence may indicate geothermal potential, they can also cause problems in executing a geothermal project.	The Global Earthquake Model (GEM) Global Seismic Hazard Map (version 2018.1) depicts the geographic distribution of the Peak Ground Acceleration (PGA) with a 10% probability of being exceeded in 50 years, computed for reference rock conditions (shear wave velocity, VS30, of 760-800 m/s).	M. Pagani, J. Garcia-Pelaez, R. Gee, K. Johnson, V. Poggi, R. Styron, G. Weatherill, M. Simionato, D. Viganò, L. Danciu, D. Monelli (2018). Global Earthquake Model (GEM) Seismic Hazard Map (version 2018.1 - December 2018), Doi: 10.13117/GEM-GLOBAL-SEISMIC-HAZARD-MAP-2018.
Subsurface Favorability	Global	Tectonics	Global_Sedimentray_Basins_Evenick_2021	Sedimentary Basins are caused by extension (rifting) that thins the lithosphere, increasing the heat from the mantle. The heat generated by these geological processes can persist for a considerable period after rifting has occurred. Understanding the time since	A global sedimentary basin map was constructed with 764 basins. A conscious effort was undertaken to draft an updated and revised global sedimentary basin map, which utilizes information from literature in	Evenick,J.C., 2021, Glimpses into Earth's history using a revised global sedimentary basin map, Earth-Science Reviews, Volume 215, 2021, 103564, ISSN 0012-8252, https://doi.org/10.1016/j.earscirev.2021.103564.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
				rifting helps assess the availability and sustainability of the heat source for geothermal energy production. The formation age of each of these basins is included in the metadata. In addition different sedimentary basins can have varying thermal conductivities, which affect the ability of rocks to transfer heat.	the form of stratigraphic columns, gravity data, geological maps, well data, seismic data, previous compilations, and other sources of information that can be utilized for large-scale basin analysis, studies, and assessments.	https://sites.google.com/site/jevenick/Home/supplemental-files.
Subsurface Favorability	USA	Advection	USA_Well_Springs_OIT	Thermal springs are surface manifestations of geothermal activity. When hot water or steam from the Earth's interior reaches the surface, it creates these springs. Their presence serves as a visible and easily identifiable indicator of the underlying geothermal reservoir.	The data is gathered from the Oregon Institute of Technology Geo-Heat Center co-located geothermal resources study in 2004. Data presents the available information on wells and springs for the geothermal sites in Arizona, California, Colorado, Idaho, Montana, North Dakota, Nebraska, New Mexico, Nevada, Oregon, Texas, Utah, Washington and Wyoming. Database contains information concerning the site name, county, depth, temperature, flow rate, and total dissolved solid (TDS).	OIT
Subsurface Favorability	USA	Advection	USA_Thermal_Springs_AASG_GDS	Thermal springs are surface manifestations of geothermal activity. When hot water or steam from the Earth's interior reaches the surface, it creates these springs. Their presence serves as a visible and easily identifiable indicator of the underlying geothermal reservoir.	This repository contains document artifacts for an information exchange for thermal springs observations. The Thermal Spring URI for a particular spring is the cross-referencing link (foreign key) used to associate the spring record, temperature measurements, chemistry and other information from a particular spring. Each entry is for one spring. Multiple observations (such as: temperature observations, chemical analyses) from the same spring would be entered on separate, appropriate spreadsheets/templates.	AASG_GDS

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Subsurface Favorability	USA	Advection	USA_Thermal_Springs_USGS	Thermal springs are surface manifestations of geothermal activity. When hot water or steam from the Earth's interior reaches the surface, it creates these springs. Their presence serves as a visible and easily identifiable indicator of the underlying geothermal reservoir.	Data includes available information on location, temperature, flow rate, acidity (pH) and Total Dissolved Solid (TDS) content of 2,071 wells and springs which are representative of 1,168 low-temperature geothermal systems identified in 26 States. Names used in this table are generally those used on the state geothermal resource maps. If the site is unnamed, a nearby feature is usually given for reference. The site is identified as a spring or well, and alternate names are sometimes given in parentheses. The data is obtained from the United States Geological Survey (U.S.G.S.) Open-File Report 83-250 (Table-1) titled Low-Temperature (Less Than 90°C) Geothermal Systems in The United States; Reference Data for U.S.G.S. Circular 892. The report was originally published in 1982 and updated in 2015 (report forthcoming from USGS). Detailed geochemistry data and reservoir temperature estimates (from different geothermometer calculations) are also available in the original report.	Reed, M J, Mariner, R H, Brook, C A, and Sorey, M L. Selected data for low-temperature (less than 90{sup 0}C) geothermal systems in the United States: reference data for US Geological Survey Circular 892. United States: N. p., 1983. Web. doi:10.2172/5456555.
Subsurface Favorability	USA	Advection	USA_Volcanos_GMNA	Volcanoes are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction. Volcanic regions tend to have higher geothermal temperatures due to the nearby magma chambers. These elevated temperatures can result in superheated geothermal fluids and steam,	A collection of geospatial files, map images, publication documentation, and informational resources in support of the Geologic Map of North America.	https://ngmdb.usgs.gov/gmna/#gmnaAbout.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
				which are ideal for generating electricity efficiently.		
Subsurface Favorability	USA	Advection	USA_Volca-nic_Vents_AASG_GDS	Volcanoes are evidence of advection, the transport of heat by a moving fluid or a rock mass. This process is usually much faster, and, therefore, more efficient in equilibrating temperature fields, than heat conduction. Volcanic regions tend to have higher geothermal temperatures due to the nearby magma chambers. These elevated temperatures can result in superheated geothermal fluids and steam, which are ideal for generating electricity efficiently.	This repository contains document artifacts for an information exchange for volcanic vent observations. This simple content model is intended to identify recently active volcanic vents that may indicate areas of active hydrothermal systems. Detailed geophysical or geodetic information related to active magma movement and prediction of eruptive activity are out of scope.	AASG_GDS
Subsurface Favorability	USA	Advection	USA_Isolated_-Geothermal_Sys-tems_USGS	Potential Geothermal Sites.	Data includes resource temperature estimates and beneficial heat/thermal energy available for Isolated low-tem-perature (<90°C) geothermal systems (906 of 978 systems have coordinate information and are presented in GT Prospector). Temperature values were estimated through the use of chemical geother-mometer calculations and from information on flow rate, temperature gradient, and geologic environment. The three temperature values were used to form a triangular density distribution for calculation of the energies for each system. The geologic province is also given for each system to provide a key to the summarized values for isolated systems.	The data is obtained from the United States Geological Survey (USGS) Open-File Report 83-250 (Table-2) titled Low-Temperature (Less Than 90°C) Geothermal Systems in The United States; Reference Data for USGS Circular 892. The report was originally published in 1982 and updated in 2015 (report forthcoming from USGS).
Subsurface Favorability	USA	Advection	USA_Developing_-Geothermal_Proj-ects_NREL	Potential Geothermal Sites.	Developing geothermal projects information aggregated from	NREL

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
					lists of geothermal projects under development obtained from the Geothermal Energy Association 2014 Annual U.S. & Global Geothermal Power Production Report and SNL Financial LC. In the event that a project was listed in both datasets, GEA data was used. Development geothermal project status and location verified and corrected when possible independently by NREL. When available, BLM LR2000 Lease information was compared with other data sources to verify developing project location. The developing status that is stated for each location is an NREL-defined status which is based on the terminology used by both 2014 Annual U.S. & Global Geothermal Power Production Report and SNL Financial LC. Because of the uncertainty inherent in data surrounding projects under development, NREL cannot and does not guarantee the accuracy of this data.	
Subsurface Favorability	USA	Advection	USA_Geother-mal_Ar-eas_AASG_GDG	Potential Geothermal Sites.	This repository contains document artifacts for an information exchange for Geothermal Areas. The artifacts include an Excel Workbook that defines and documents the content model, and an XML schema that implements the model. This exchange is for polygon features representing geothermal areas. These data will have general information about land ownership, tempera-ture characterization, geologic setting and information source.	AASG-GDS Database

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Subsurface Favorability	USA	Tectonics	USA_Great_Ba-sin-Quaterna-ry-Faults_USGS	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	This database contains the results of slip tendency and dilation tendency analysis of Quaternary faults in the Great Basin region, including parts of Arizona, California, Idaho, Nevada, Oregon, Utah, and Wyoming. This effort was undertaken to help identify faults and fault segments that are appropriately oriented to be stress-loaded for slip or to dilate under the ambient stress conditions. Both conditions may make such faults likely to host as-yet-undiscovered hydrother-mal processes. Slip tendency and dilation tendency were calculated for all fault segments in a publicly available fault database modified after the U.S. Geology Survey Quaternary Fault and Fold Database.	USGS
Subsurface Favorability	USA	Tectonics	USA_Active_-Faults_-AASG-GDS	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	This repository contains document artifacts for an information exchange for active fault observations. Design is focused on faults portrayed as line segments. The content model is based on the GeoSciML thematic view for ShearDisplacementStructure (see https://www.see-grid.csiro.au/wiki/bin/view/CGI-Model/GeoSciML-ThematicViewModel), extended with some convenience properties specific to young fault structures. Active in this context denotes that there is compelling evidence of fault displacement during the Quaternary.	AASG-GDS Database

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Subsurface Favorability	USA	Tectonics	USA_Quaternary_-Faults	Faults and fractures can serve as pathways for geothermal fluids to migrate from the deeper reservoir to the surface; they can also enhance heat transfer within the Earth's crust. Deeper faults may provide a more efficient conduit for the transport of heat from the deeper, hotter portions of the Earth's crust or mantle to shallower depths. This can result in higher geothermal temperatures at accessible depths. Conventional geothermal systems are strongly structurally controlled with favorable locations at structural bends, transfer zones, termination zones, transtensional pull apart zones, relay ramps, step-overs, and accommodation zones.	This database was used to create the fault-source characterization in the National Seismic Hazard Maps. For the hazard maps, both the fault surface trace and the metadata are simplified representations of the geometry and behavior of the fault, based on geologic interpretation.	U.S. Geological Survey, Quaternary fault and fold database for the United States: https://ww-w.usgs.gov/natural-hazards/earth-quake-hazards/faults.
Surface Suitability	Global	Potential Barriers	Protected Areas	This layer is required for surveying and addressing public awareness issues. In some protected areas drilling activity will be prohibited.	The World Database on Protected Areas (WDPA) is the most up-to-date and complete source of information on protected areas, updated monthly with submissions from governments, non-governmen-tal organizations, landowners, and communities. It is managed by the United Nations Environ-ment Programme's World Conservation Monitoring Centre (UNEP-WCMC) with support from IUCN and its World Commission on Protected Areas (WCPA).	UNEP-WCMC and IUCN (2023), Protected Planet: The World Database on Protected Areas (WDPA) [On-line], [09/2023], Cambridge, UK: UNEP-WCMC and IUCN Available at: www.protected-planet.net.
Surface Suitability	Global	Surface Risk	Overall Water Risk	Conventional Geothermal has the second highest water consumption of all renewable and non-renewable power plants. Open-loop systems need to replenish the water inside their under-ground reservoirs to ensure an ongoing supply but the production process can also cause water quality and contamina-tion problems; sulfur, salts and CO2 and minerals are often co-produced with the	Aqueduct™ water risk frame-work, combines 13 water risk indicators—including quantity, quality, and reputational risks—into a composite overall water risk score. Key elements of Aqueduct, such as overall water risk, cannot be directly measured and therefore are not validated. Aqueduct remains	Hofste, R. W., Kuzma, S., Walker, S., Sutanudjaja, E. H., Bierkens, M. F. P., Kuijper, M. J. M., Sanchez, M. F., Beek, R. V., Wada, Y., Rodríguez, S. G., & Reig, A. P. (2019). AQUEDUCT 3.0: Updated decision-relevant global water risk indicators. In. Washington, DC: World Resources Institute. doi: 10.46830/writn.18.00146.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
				water with potential groundwater contamination issues. Ground water assessment is a critical part of screening. Unconventional geothermal will have minimum water use.	primarily a prioritization tool and should be augmented by local and regional deep dive.	
Surface Suitability	Global	Transmis-sion Capacity	Slope in degrees from a terrain DEM	Generally, the most suitable locations for geothermal well pads are almost flat areas (<5%) to very gently sloping areas (6–15%), these values ensure minimal environmen-tal disturbances (Noorollahi et al. 2008). These range of values, which were also used by Mungania and Shako (2007) and Shako and Wamalwa (2014), were used in generating the slope criteria.	NASA DEM is a reprocessing of STRM data, with improved accuracy by incorporating auxiliary data from ASTER GDEM, ICESat GLAS, and PRISM datasets. The most significant processing improvements involve void reduction through improved phase unwrapping and using ICESat GLAS data for control.	NASA JPL (2020). NASADEM Merged DEM Global 1 arc second V001 [Data set]. NASA EOSDIS Land Processes DAAC. Accessed 2020-12-30 from doi:10.5067/MEaSUREs/NASA-DEM/NASADEM_HGT.001
Surface Suitability	Global	Estimated Demand	VIIRS Nighttime Light Annual Composites	Nighttime lights data comes from images of the earth's surface taken at night. Brighter areas denote greater concentra-tion of streetlights and light from other ground sources. Annual composites show average light intensity removing noise from artifacts like cloud cover and the aurora borealis. All else equal, higher light intensity may indicate greater likelihood of high electricity demand.	This layer is used as an input feature for machine learning algorithms for estimating electricity and heating demand.	Elvidge, C.D, Zhizhin, M., Ghosh T., Hsu FC, Taneja J. Annual time series of global VIIRS nighttime lights derived from monthly averages:2012 to 2019. Remote Sensing 2021, 13(5), p.922, doi:10.3390/rs13050922
Surface Suitability	Global	Estimated Demand	Land Use/Land Cover	The Land Use Land Cover (LULC) data from Microsoft is a global dataset describing how land is being used and what types of surfaces cover the Earth. It is derived from satellite imagery and machine learning algorithms that classify land as belonging to "Water," "Trees," "Grass," "Flooded Vegetation," "Crops," "Scrub/Shrub," "Built Area," and "Bare Ground," among others. Local and nearby land use can inform machine learning algorithms about the likelihood of different types of local economic activity.	This layer is used as an input feature for machine learning algorithms for estimating electricity and heating demand.	Karra, Kontgis, et al. "Global land use/land cover with Sentinel-2 and deep learning." IGARSS 2021-2021 IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2021.

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Surface Suitability	Global	Estimated Demand	Ookla Global Fixed and Mobile Network Performance Map Tiles	Ookla speed tests are a popular tool for measuring internet connection speed and performance. The tests provide information on download and upload speeds, latency, and other performance metrics. The tests are available online and historical use data is aggregated and provided for free download and use. All else equal, higher internet speeds may denote higher income, wealth, and energy demand.	This layer is used as an input feature for machine learning algorithms for estimating electricity and heating demand.	Ookla. Speedtest by Ookla Global Fixed and Mobile Network Performance Map Tiles, 2022. https://github.com/teamookla/ookla-open-data.
Surface Suitability	Global	Estimated Demand	Google Open Buildings	The Google Open Buildings dataset provides building footprints across Africa and Southeast Asia and was created using high-resolution satellite imagery and convolutional neural network and polygonization models. Google reports 80% and 90% precision levels for their building detections. The data is freely available for download. We combine Google Open Buildings with other buildings layers to create a composite building footprint dataset that serves as the foundation for our electricity and heating demand analyses. We also compute attributes like local building density and building rooftop area.	This layer is used as an input feature for machine learning algorithms for estimating electricity and heating demand.	W. Sirko, S. Kashubin, M. Ritter, A. Annkah, Y.S.E. Bouchareb, Y. Dauphin, D. Keysers, M. Neumann, M. Cisse, J.A. Quinn. Continental-scale building detection from high resolution satellite imagery. arXiv:2107.12283, 2021.
Surface Suitability	Global	Estimated Demand	Microsoft Global Machine Learning (ML) Building Footprints	The Microsoft Building Footprints dataset uses Bing Maps imagery and convolutional neural network and polygonization models to produce a worldwide building footprint dataset. Microsoft reports precision and recall metrics of 94.4% and 70.9%, respectively for buildings across the African continent. The data is freely available for download. We combine Microsoft Open Buildings with other buildings layers to create a composite building footprint dataset that serves as the foundation for our electricity and heating demand analyses. We also compute attributes like local building density and building rooftop area.	This layer is used as an input feature for machine learning algorithms for estimating electricity and heating demand.	Microsoft. Worldwide building footprints derived from satellite imagery (GlobalMLBuildingFootprints), 2023 Accessed July 2023, https://github.com/microsoft/GlobalMLBuildingFootprints

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
Surface Suitability	Global	Estimated Demand	OpenStreetMap Buildings and Places of Interest	OpenStreetMap makes manually-annotated building footprint and places of interest labels freely available. We combine OpenStreetMap Buildings with other buildings layers to create a composite building footprint dataset that serves as the foundation for our electricity and heating demand analyses. We also compute attributes like local building density and building rooftop area. We additionally employ point of interest labels as ground truth data describing productive uses of energy. We use these labels for statistical characterization of the spatial distribution of heating. demand.	OpenStreetMap (OSM) is an open collaborative project, aimed at creating a free, editable map of the world. It is maintained by a global community of volunteers and contains georeferenced data on roads, buildings, landmarks, waterways, bodies of water, and railways, among other features.	OpenStreetMap contributors. Planet data retrieved from https://planet.osm.org, 2023. https://www.openstreetmap.org
Surface Suitability	Global	Power Lines	High Voltage Power Lines	Geothermal power plants generate electricity, which needs to be transmitted to consumers. Nearby existing power lines are beneficial as they reduce the need for additional infrastructure investment to connect the geothermal plant to the power grid. We specifically filter the OpenStreetMap power lines dataset to isolate high voltage grid lines for further analysis. These high voltage grid lines are defined as those with over 35 kV ratings.	OpenStreetMap (OSM) is an open collaborative project, aimed at creating a free, editable map of the world. It is maintained by a global community of volunteers and contains georeferenced data on roads, buildings, landmarks, waterways, bodies of water, and railways, among other features.	OpenStreetMap contributors. Planet data retrieved from https://planet.osm.org, 2023. https://www.openstreetmap.org
Surface Suitability	Global	Power Lines	Medium Voltage Power Lines (Estimated)	Geothermal power plants generate electricity, which needs to be transmitted to consumers. Nearby existing power lines are beneficial as they reduce the need for additional infrastructure investment to connect the geothermal plant to the power grid.	Using state-of-the-art algorithms in geospatial data analysis, the GridFinder dataset is the first composite map of the global power system with an open license. Note that this dataset is derived, and represents an approximate representation of existing MV power lines.	Arderne, C., Zorn, C., Nicolas, C. et al. Predictive mapping of the global power system using open data. Sci Data 7, 19 (2020). https://doi.org/10.1038/s41597-019-0347-4
Surface Suitability	Nigeria	Estimated Demand	Estimated Electricity Demand	Electricity demand is a key input for analyzing geothermal surface suitability. Heat from geothermal resources can be converted to electricity and drive economic activity.	This dataset was created using the LItLDF model. The model is trained using remote sensing and observed metered consumption data. The model is	Lee, S.J., Taneja, J.. Estimating Electricity Demand at Scale (in prep) Lee, S.J., Multimodal Data Fusion for Estimating Electricity Access and Demand, Doctoral Thesis, Massachu-

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
					then used to estimate demand in areas lacking consumption data at the building-level. This data layer represents grid cells at 30 arc-second resolution. The value of each grid cell corresponds to total electricity demand of all buildings residing in each grid cell.	setts Institute of Technology, 2023
Surface Suitability	Nigeria	Estimated Demand	Estimated Electricity Demand (Building-Level)	Electricity demand is a key input for analyzing geothermal surface suitability. Heat from geothermal resources can be converted to electricity and drive economic activity.	This dataset was created using the LItLDF model. The model is trained using remote sensing and observed metered consumption data. The model is then used to estimate demand in areas lacking consumption data at the building-level.	Lee, S.J., Taneja, J.. Estimating Electricity Demand at Scale (in prep) Lee, S.J., Multimodal Data Fusion for Estimating Electricity Access and Demand, Doctoral Thesis, Massachusetts Institute of Technology, 2023
Surface Suitability	Nigeria	Estimated Demand	Estimated Heating Demand	Heating demand is a key input for analyzing geothermal surface suitability. Heat from geothermal resources can be directly used for commercial and industrial applications.	This heating demand dataset was created by comparing the spatial distribution of bottom-up models based on building labels and top-down models of economic activity, including those characterizing electricity demand. Learned distributions are finally scaled to sum to heating demand figures from aggregate statistics. This data layer represents grid cells at 30 arc-second resolution. The value of each grid cell corresponds to total electricity demand of all buildings residing in each grid cell.	Lee, S.J., . Estimating Heating Demand for Geothermal Energy at Scale (in prep)
Surface Suitability	Nigeria	Estimated Demand	Estimated Heating Demand (Building-Level)	Heating demand is a key input for analyzing geothermal surface suitability. Heat from geothermal resources can be directly used for commercial and industrial applications.	This heating demand dataset was created by comparing the spatial distribution of bottom-up models based on building labels and top-down models of economic activity,	Lee, S.J., . Estimating Heating Demand for Geothermal Energy at Scale (in prep)

	Geographic Module	Discipline Module	Discipline Layer Name for Data Library	Why This Layer is Helpful	User Notes	Citation
					including those characterizing electricity demand. Learned distributions are finally scaled to sum to heating demand figures from aggregate statistics.	
Subsurface Favorability	Global	Weighted Overlay Analysis	Subsurface Favorability	Weighted overlay analysis (WOA) is a Geographic Information System (GIS)-based technique that enables the combination of different spatial data layers while assigning varying weights based on their relevance and significance for a specific objective. In the context of geothermal exploration, weighted overlay analysis serves to identify and prioritize areas most suitable for geothermal development, considering various geospatial factors like geology, geophysics, temperature, depth, seismic activity, volcanism, and more.	Weights were assigned by the Phase 1 subsurface team.. Class-based raster maps, ranked on a scale from 0 to 5, were generated using Google Earth Engine.	A collaboration between Project InnerSpace and Google.

Appendix 2 - Techno-Economic Sensitivity Tool (TEST)

Parameter	Category	Definition	Why This Parameter is Helpful	Citation
Surface Favorability	From GeoMap™	This variable is the outcome of the surface WOA (weighted overlay analysis) in GeoMap™, merging the input of multiple data layers as described in GeoMap™. Class-based raster maps, ranked on a scale from 0 to 5, were generated using Google Earth Engine, with higher values representing better favorability for geothermal developments.	This variable facilitates the decision on where to explore techno-economic sensitivities for geothermal developments, considering surface demand and availability of infrastructure, among other variables.	A collaboration between Project InnerSpace and Google 2023.
SubSurface Favorability	From GeoMap™	This variable is the outcome of the subsurface WOA (weighted overlay analysis) in GeoMap™, merging the input of multiple data layers as described in GeoMap™. Class-based raster maps, ranked on a scale from 0 to 5, were generated using Google Earth Engine, with higher values representing better favorability for geothermal developments. Weights were assigned by the Phase 1 subsurface team.	This variable facilitates the decision on where to explore techno-economic sensitivities for geothermal developments, considering heat flow, thickness of sedimentary layers and lithosphere, among other variables.	A collaboration between Project InnerSpace and Google 2023.
Geothermal Gradient	From GeoMap™	The global geothermal gradient map was created by Project Innerspace utilizing the HFgrid14.csv: preferred heat flow prediction (Lucazeau 2019) on a 0.5°x0.5° grid and with 14 observables and combining it with a range of thermal conductivities for cratons and sedimentary basins.	The geothermal gradient is the rate at which temperature increases with depth in the Earth's crust. It serves as an indicator of the subsurface temperature conditions relative to well depth. A higher geothermal gradient indicates a more rapid increase in temperature with depth.	Project InnerSpace 2023 based on Lucazeau 2019.
Depth to Basement	From GeoMap™	Global continental sedimentary thickness, where estimates in Africa and Arabia are from Holdt and White (in prep) and estimates outside of these regions use sediment thickness data from the CRUST 1.0 model (Laske et al., 2013) https://igp-pweb.ucsd.edu/~gabi/crust1.html.	The depth of sedimentary thickness is a crucial factor in geothermal drilling cost efficiencies. It indicates when a well reaches the crystalline basement, which is significantly more expensive to drill.	Global continental sedimentary thickness, where estimates in Africa and Arabia are from Holdt and White (in prep) and estimates outside of these regions are from Laske et al., 2013 (https://igp-pweb.ucsd.edu/~gabi/crust1.html).
Surface Temperature	From GeoMap™	SBIO1 = Annual Mean Temperature. Soil temperature layers were calculated by adding monthly soil temperature offsets to monthly air-temperature maps from CHELSA (date range 1979-2013) (Karger et al. 2017, Sci Data). These soil temperature layers were then used to calculate annual means, temperature ranges, standard deviation, warmest and coldest months and quarters for Soil Bioclim Layers between 0-5 cm and 5-15cm. This layer represents the soil bioclim between 0-5 cm.	Surface temperature influences base temperature of fluid at service, thus indicating the required drilling depth to achieve target geofluid temperatures at surface.	Johan van den Hoogen, Jonas Lembrechts, SoilTemp, Ivan Nijs, & Jonathan Lenoir. (2021). Global Soil Bioclimatic variables at 30 arc second resolution (Version 1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.4558732

Parameter	Category	Definition	Why This Parameter is Helpful	Citation
Production Temperature	Temperature	This is the water temperature at point of entry to surface facilities, accounting for losses in the well and surface network; the lower bound constraint is 80°C because the GeoMap™ Beta Tool focuses on deep geothermal targets, rather than shallow heat pump applications. The upper bound is constrained to 320°C as we do not currently have sufficient technical data to support operational performance in excess of 320°C.	This temperature is defined by the user based on the desired surface use case.	-
Temperature Gradient Uncertainty	Temperature	The user may modify the temperature gradient coming from maps with an uncertainty range between plus and minus 20%.	This variable allows to account for the inherent uncertainty in temperature gradient maps.	-
Number of Producing Wells	Subsurface	Number of wells harvesting heat from the subsurface.	Together with flow rate, this variable defines the magnitude of the geothermal project (i.e. how much energy may be produced in the plant). GeoMap Beta operates under the philosophy of doublets (one injection well per production well)	-
Flowrate per Well	Subsurface	Bounded conditions of 25 to 100 kg/s per production well based on observed production tests and minimum viable technical levels.	Together with the number of wells, this variable defines the magnitude of the geothermal project (i.e. how much energy may be produced in the plant).	-
Sedimentary Drilling Cost Adjuster	Subsurface	GeoMap™ Beta separates drill cost estimation between sedimentary rock and basement rock. The estimation of drilling cost in the sedimentary rock segment uses a simplified cost as a function of depth approach, without accounting for specific rock properties. Users are allowed to modify the drilling cost per foot as a percentage of the reference value. Beta relies on current oil and gas unconventional drilling data from operators in the deep, high-temperature Haynesville Shale (SWN, 2023, CHK, 2022 and CRK, 2023) to define a reference drill cost per measured foot at 300 $/ft. That metric is then increased by an assumed 25% to transform 5" oil and gas well diameters to an assumed 7" geothermal well diameter to yield a reference drilling cost of 375 $/ft. Drilling cost bounds are defined as a multiplier of the reference drilling cost; the sliders bounds are defined in a range between 1000 $/ft (265% increase) and 150 $/ft (40% decrease with respect to baseline): the former is the high end of the historic geothermal drilling cost data showed in Frash, 2023 and the latter is consistent with a potential technology development equivalent to other renewable resources, and consistent with "ATB" advanced scenario (NREL, 2023) and "Earthshot" scenario in the USA (Augustine, 2023). Note that no exploration costs, pilot hole	Drilling costs are a critical variable to define the economic viability of a geothermal project, but are subject to significant price volatility over time. The Beta tool has collected public historic drilling cost information on shallower hydrothermal wells (wide diameter), as well as current public information from Haynesville Shale operators, providing current market pricing for deep and hot wells (small diameter). Beta assumes a 1km horizontal section in all wells, and assumes a 20% increase in drilling cost when moving from small diameter to wide diameter based on conversations with industry experts. This sedimentary drilling cost curve is meant to establish a current baseline for drilling cost in established Oilfield Service Markets from which the user can vary estimates to reflect dynamics of a selected project market.	CHK Chesapeake Energy. 2022. Premium Rock, Returns, Runway. Barclays CEO Energy-Power Conference. CRK Comstock Resources. 2023. Comstock Resources Investor presentation. SWN Southwestern Energy. 2023. Investor presentation. Frash, L. et al. 2023. A Proposal for Safe and Profitable Enhanced Geothermal Systems in Hot Dry Rock. Proceedings 48th Workshop on Geothermal Reservoir Engineering Stanford University. SGP-TR-224 Augustine, C. et al. 2023. Enhanced Geothermal Shot Analysis for the Geothermal Technologies Office. NREL/TP-5700-84822. NREL, 2023. Annual Technology

Parameter	Category	Definition	Why This Parameter is Helpful	Citation
		costs or other 'pre-drill' costs are assumed in the GeoMap™ Beta methodology.		Baseline https://www.nrel.gov-/analysis/data-tech-baseline.html
Basement Drilling Cost Multiplier	Subsurface	GeoMap™ Beta separates drill cost estimation between sedimentary rock and basement rock. The GeoMap™ Beta relies on a simplified approach for estimating basement drilling cost as a multiple of the calculated sedimentary drilling cost per foot given a relative paucity of basement drilling cost data relative to sedimentary targets. The user can select a multiple between 1x to 4x which is multiplied by the calculated sedimentary drill cost per foot, as described above, with an initial value at 2. This cost factor is multiplied by the basement drilling length, and horizontal segment, as defined by the depth to target temperature and depth to basement data, to calculate the basement drilling cost. Note that the basement drill cost methodology also does not account for specific rock properties in the basement.	Basement drilling costs are currently much higher than sedimentary costs as oil and gas has traditionally not targeted these formations. Basement drilling efficiency is very likely to experience step changes in efficiency over the coming decade and therefore is an important separate variable to consider than sedimentary drilling cost.	-
Power Plant Efficiency Increase Over Baseline	Surface - Power	Heat-to-power conversion is simplified as a direct function of production temperature, using efficiency correlations of existing power cycles from Beckers (2019). The GeoMap™ Beta does not automatically adjust user defined capital costs at higher conversion efficiencies. In this work, we utilize sub-critical ORC up to 190°C and double flash at higher temperatures.	To consider technology improvements that may enhance the conversion efficiency of heat into power as a function of temperature, the user can vary turbine conversion efficiency over a preset baseline. This approach that modifies the efficiency relative to a baseline is meant to reduce incoherent scenarios relative to production temperature, but still provide for the potential contribution of next generation technology (e.g. supercritical CO2 turbines), with slider bounds defined as 0 - 25%.	Beckers, K. et al. 2019. GEOPHIRES v2.0: updated geothermal techno-economic simulation tool. Geotherm Energy (2019) 7:5
Power Plant Costs ($/kW)	Surface - Power	GeoMap™ Beta applies a simplified approach to determine the cost of surface facilities, by applying a formula of $/kW that does not consider the size of the plant in the cost of the facilities. Power Plant cost bounds are defined in a range between 1000 $/kW and 4000 $/kW.	Geothermal requires large upfront costs, and Surface facilities costs are a critical variable to define the economic viability of a geothermal project.	-
Surface Heat Exchanger Costs	Surface - Heat	This allows the user to adjust the capital cost per unit of heat capacity ($/kWth) to account for varying levels of surface heat exchange infrastructure and end use facility integration. GeoMap ™ Beta assumes a default amount of $100/kWth based on Beckers (2017). Slider bounds are defined as 50-150 $/kWth.	Geothermal requires large upfront costs, and Surface facilities costs are a critical variable to define the economic viability of a geothermal project.	Beckers, K. et al. 2017. Performance, Cost, and Financial Parameters of Geothermal District Heating Systems for Market Penetration Modeling under Various Scenarios. Proceedings 42nd Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California. SGP-TR-212

Parameter	Category	Definition	Why This Parameter is Helpful	Citation
Capacity Factor	Surface - Heat	Allows the user to define the amount of output from the geothermal installation relative to nameplate capacity. Most contracts require base load heat supply (>90%), but some installations or heat use scenarios may operate at lower levels of efficiency or require higher levels of reserve capacity.	One of the strengths of geothermal plants is related to the ability to operate with high capacity factors, providing baseload energy without the need to add storage facilities and their related costs.	-
Import Cost of Electricity	Surface - Heat / Cool	Asks the user to input estimated local power prices for any given project location. Heat-only projects will need to purchase power to run well pumps as the project will not generate power for consumption. Reference value is set at 0.07 $ / kWhe. The local power price is multiplied by annual required pump power to calculate a power purchase cost of output sold.	Direct-use cases rely on a external source of electricity to power the facilities.	-
Absorption Chiller Cost	Surface - Cool	Allows the user to adjust the capital cost per unit of cooling output in refrigeration tons ($/ton) to account for various heat to cooling conversion equipment. GeoMap™ Beta assumes a default amount of $2000/ton based on [DOE, 2017]. Slider bounds are defined as 1800-6000 $/ton based on [DOE, 2017].	Geothermal requires large upfront costs, and Surface facilities costs are a critical variable to define the economic viability of a geothermal project.	DOE-EE, 2017. Report 1608. Combined Heat and Power Technology Fact Sheet Series.
Absorption Chiller Coefficient of Performance ('COP')	Surface - Cool	Allows the user to adjust the ratio of electrical power consumed relative to cooling output. GeoMap™ Beta assumes a default amount of 0.8 based on [DOE, 2017]. Slider bounds are defined as 0.7-1.4 based on [DOE, 2017].	This allows the user to consider future performance efficiency improvements and in concert with the import cost of electricity will define power purchase costs for the project.	DOE-EE, 2017. Report 1608. Combined Heat and Power Technology Fact Sheet Series.
Capital Expenditure Subsidy	Economics	Users can apply a percentage of CAPEX subsidy to explore what incentive policies may achieve in terms of assuring the viability of geothermal projects. In the GeoMap™ Beta the capex subsidy amount equals a cash payout at the commencement of production and does not consider specific regulatory regimes of project location.	This variable reflects the incentives that may be in place to facilitate the penetration of renewable resources that require high upfront costs.	-
Annual OPEX as % of Total CAPEX	Economics	Annual operating and maintenance costs are calculated as a percentage of total capital cost. The User may modify the default 2% value.	Even if typically low, operating and maintenance costs are required to evaluate the payout price of a geothermal project.	-
Wells and Plant Construction Time	Economics	Users may modify the time to build the wells and plants. The GeoMap™ Beta assumes the project is 'shovel-ready' and does not consider exploration or permitting time in its calculations.	Time required to build the plant and drill the wells will delay the 1st watt produced in the plant and negatively affect the economics.	-
Discount Rate	Economics	Discount rate considers the minimum interest rate set by national banks for lending to other banks. Users may modify the discount rate; the default is zero.	In projects with high upfront costs, a high discount rate will negatively affect the payout price of the project.	-

Parameter	Category	Definition	Why This Parameter is Helpful	Citation
Target Depth	Output	Once the user selects a production temperature, TEST computes the necessary depth to achieve the target temperature. This calculation takes into consideration the temperature gradient, surface temperature at the chosen location, and temperature losses incurred during flow from the reservoir to the process inlet	Depth defines the cost of drilling required to achieve the target temperature at the surface	-
Average Net Energy Sales	Output	Yields the available power / thermal energy for sale, after subtracting parasitic losses	Defines the number of wells and flowrate required for a specific project, and informs the calculations of payout price	-
Cost Per Well	Output	Calculates the cost of the well by accounting for both sedimentary and basement drilling lengths, and the cost per unit length coming from the sliders of Sedimentary Drilling Cost Adjuster and Basement Drilling Cost Multiplier	Informs the CAPEX calculations, but also provides guidance to the user to select a sedimentary drilling cost Adjuster.	-
Average Drilling Cost	Output	Yields the average cost per unit length in the production and injection wells, including both the sedimentary and basement sections	Provides guidance to the user to select a sedimentary drilling cost Adjuster	-
Surface Facility Cost	Output	Calculates the cost of surface facilities (Flash/Rankine, heat exchanger or absorption chiller) by multiplying the Plant Cost ($/kWe or $/kWth) by the installed capacity	Informs the CAPEX calculations	-
Simple Pre-Tax Payout Price	Output	Calculates a pretax, real, levelized price per unit of output (i.e. MWh electric, Thermal BTU or cooling ton) for the production life to match discounted cash inflows and outflows based on the user's inputs	Simple Payout Price may be comparable to some formulations of Levelized Cost of Energy (LCOE, LCOH or LCOC)	-
Lifetime Project Generation	Output	Represents the aggregate of energy generated annually over the life of the project	Provides guidance to the user to select the magnitude of the project to explore	-
Foregone CO2 Emissions vs Gas	Output	Amount of avoided CO2 emissions (million kg) over the life of the project. The calculator for the power generation module assumes displacement of a natural gas CCGT baseload plant which the EIA estimates has an emissions intensity of 976 lb / MWh in the USA	The value of geothermal as an energy resource shall consider more variables than payout price and other economic variables; several countries are allowed to pay for a premium to implement more clean, baseload energy with lower dependance from other countries	EIA, 2021. Electric power sector CO2 emissions drop as generation mix shifts from coal to natural gas. (link)
Surface Footprint	Output	Estimates land requirements for geothermal wells and plan using as reference the data published by Lovering et al (2022), with a median value of 45 ha/TWh/y per unit of electricity production	The value of geothermal as an energy resource shall consider more variables than payout price and other economic variables; among renewables, geothermal has the smallest surface footprint	Lovering, J., Swain, M., Blomqvist, L., Hernandez, R.R. (2022). Land-use intensity of electricity production and tomorrow's energy landscape. PLoS ONE 17(7): e0270155.