HT-ATES potential maps Maassluis and Oosterhout Fm.

1.1. Disclaimer

The following disclaimer applies to the HT-ATES potential maps for the Maassluis Fm. and Oosterhout Fm. published in May 2025 (ThermoGIS release v2.4.1).
The maps can also be found in the story map at: https://www.thermogis.nl/en/high-temperature-aquifer-thermal-energy-storage

- The HT-ATES potential maps only provide a general regional indication of potential and are not suitable for local analyses or financial decision-making due to model and economic uncertainties.
- The potential maps of four aquifers in the Maassluis and Oosterhout Formations have been created in a different way than those in the ThermoGIS-HT-ATES Mapviewer (see Geological Basis). They do not yet meet the quality requirements for ThermoGIS and should be interpreted with caution.
- The maximum flowrate is an important parameters. The flow rate is calculated based on certain guidelines (see Maximum Flowrate) which are continuously under development and will have to be updated when more knowledge on the maximum flow rate for HT-ATES is gathered in future (experimental) research and HT- and MT-ATES pilots.
- The maximum flow rates in the ThermoGIS maps are calculated with the ambient temperature of the groundwater (see Maximum Flowrate). In the DesignToolkit/MESIDO the maximum flow rate will be recalculated based on the return temperature of the network as given by the user (*work in progress, Feb 2026*)
- The CAPEX and OPEX values are indicative, as these are generated with uncertain cost input parameters. See Economic Calculations.
- For the calculation of the CAPEX and OPEX, the power map is used. The calculated power of the ThermoGIS-HT-ATES maps is dependent on network temperatures. A standard 80-40 °C network is assumed (see Technical And economic input parameters). These temperatures will change when the user enters their own values in DesignToolkit/MESIDO. It is advised that the user inserts the estimated costs themselves.

The general ThermoGIS disclaimer also applies: Disclaimer | Thermogis

1.2. Explanation

1.2.1. What is High Temperature Aquifer Thermal Energy Storage (HT-ATES)

Heat can be stored underground in various ways. High-Temperature Aquifer Thermal Energy Storage (HT-ATES) is one of them. This technique can be used to both store and produce heat (>60 °C). Storage usually takes place in the summer by injecting hot water into an aquifer. This heat can then be used again during colder periods (Figure 1).

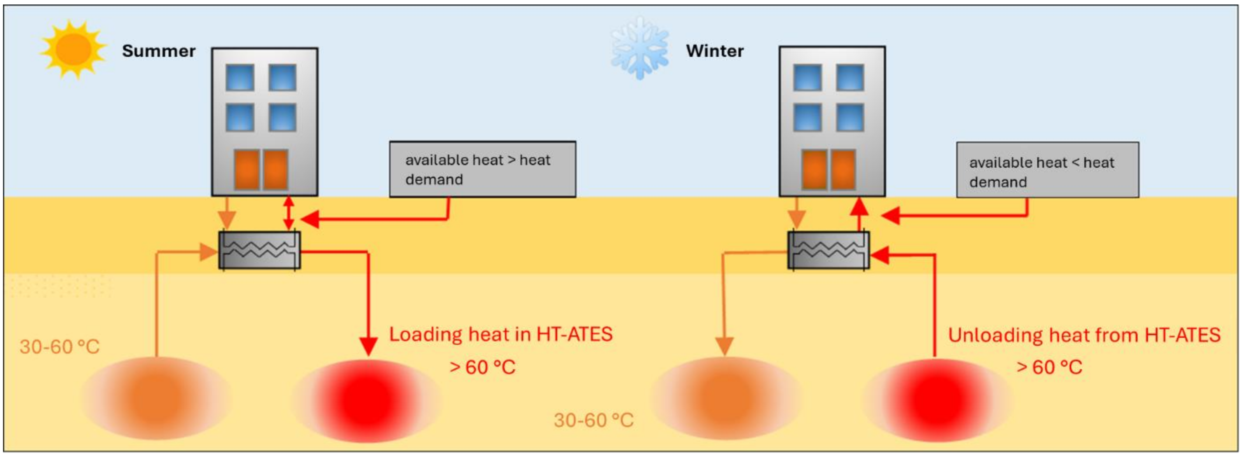

Figure 1 Working principle of an HT-ATES system. Left: In summer, water is pumped from the cold/lukewarm well (low temperature, orange), and heated with excess heat using a heat exchanger. The heated water is then injected into the warm well (red). In winter, the flow direction is reversed, and the heat is recovered from the warm well. The cooled water is pumped into the compensation well. Source: adapted from BodemenergieNL.

1.2.2. ThermoGIS-HT-ATES: purpose and method

In order to provide insight into the HT-ATES potential in the Netherlands, ThermoGIS has been expanded with an HT-ATES module. Calculations have been made to determine how suitable certain subsoil layers are for storing hot water. The calculations use:

- Maps (aquifer depth, thickness and properties)
- Constant values (technical and economic parameters, Tables 2 and 3)

The potential for HT-ATES depends heavily on the condition of the subsurface, but also on case-specific circumstances such as the temperature of the heat network. That is why assumptions for a generic heat network have been used in ThermoGIS-HT-ATES. This means that the suitability maps provide a general picture and are not suitable for detailed design.

1.2.3. Geological basis

The layers most suitable for HT-ATES are located at depths of 100 to 500 meters, such as the Maas-Sluis and Oosterhout formations. These layers have not yet been fully mapped using the ThermoGIS methodology. For this reason, the maps from REGIS II v2.2, a regional geohydrological model, have been used. Whereas ThermoGIS mainly uses 2D and 3D seismic data for the deeper layers, REGIS determines the depths and thicknesses of layers by interpolating between (shallow) borehole data. This leads to greater uncertainty, especially in areas with few boreholes.

For this reason, only the Brussels Sand Member is currently visible in the ThermoGIS-HT-ATES Map Viewer; this layer has been mapped using the ThermoGIS methodology. The potential maps of four aquifers in the Maassluis and Oosterhout Formations have been created in a different way than those in the

ThermoGIS-HT-ATES Mapviewer. They do not yet meet the quality requirements for ThermoGIS and can only be viewed within ThermoGIS under the “New developments” tab.

ThermoGIS and WarmingUP GOO are working on improving the moderately deep (~100-500 m) regional hydrogeological models. These will eventually also be used for ThermoGIS-HT-ATES.

1.2.4. Maximum flowrate

Currently, there is no generally accepted method to determine maximum flow rates for HT-ATES systems in the relevant, middle-deep depth range.
For shallow wells (<200m) in unconsolidated sand layers, three standards from the drinking water and LT-ATES (‘WKO’) sector exist. For the deep subsurface (>1000m) in consolidated rocks, there is the injection standard from the Dutch State Supervision of the Mines (SSM or ‘SodM’ in Dutch).

Therefore, the flow rate for a single well in ThermoGIS-HT-ATES is calculated using these four flow rate norms (Table 1), and the most restrictive norm will be used as the final flow rate (one flowrate for the loading and unloading phase). The final flow rate is shown in the ‘flow rate P50’ map.

Table 1 Flow rate norms with their equation. Sources: [1] NVOE (2006), [2] IF Technology. (2012), [3] Olsthoorn (1982), [4] SodM & TNO-AGE (2019)

NVOE injection norm[1,2]	$Q_{max} = 1000\left(576\,\frac{\rho_f \cdot g}{\mu}k\right)^{0.6}\sqrt{\frac{v_v}{2\cdot MFI \cdot U_{eq}}}\,2\pi r_{well}H$
NVOE extraction norm[1,2]	$Q_{max} = 7200\frac{\rho_f \cdot g}{\mu}k\;2\pi r_{well}H$ * depth factor*
Olsthoorn[3]	$P_{max} = 0.2\,z$ $Q_{max} = calculated\ with\ DoubletCalc1D\ (L = 150m)$
SODM[4]	$P_{max} = (0.135 - i)\,z$ $Q_{max} = calculated\ with\ DoubletCalc1D\ (L = 150m)$

Q_{max} max. flow rate (m^3/h)
ρ_f density of fluid (kg/m^3)
g gravitational force (9.81 m/s^2)
μ viscosity of fluid (Pa·s)
k permeability (m^2)
r_{well} well radius (m)
H filter length (m)

v_v specific clogging velocity (m/y)
MFI measured Membrane Filter Index (s/l^2)
U_{eq} equivalent full load hours per year (h/y)
z depth top of the filter (m)
L well distance (m)
i hydraulic gradient of injection water (bar/m)

* Depth factor
The depth factor is an arbitrary factor, based on experience from HT-ATES test wells, to account for higher extraction flow rates compared to the NVOE extraction standard. In practice (at the operational HT-ATES in Middenmeer) it was observed that the NVOE extraction norm is conservative for the medium-depth interval (Drijver et al., 2020). With increasing depth, the stresses on sediment increase due to the overburden and gravity. This causes the loose sand grains to be mobilised less easily. This aspect is not included in the NVOE guidelines, and therefore, these guidelines are, in general, too conservative for deeper fine-grained formations. To exceed the NVOE extraction standard, a rather arbitrary depth factor can be applied to correct for this depth effect on the extraction rates. For the

Maassluis and Oosterhout Fm. maps is chosen for a depth factor of 0.01, which means that from 100m onwards, the flow rate will be increased by a factor of [depth]/100.

1.2.5. Economic calculations

There is currently only one operational HT-ATES project in the Netherlands. As a result, reliable estimates of economic parameters such as CAPEX (capital expenditure) and OPEX (operating expenditure) are limited. The economic maps in ThermoGIS-HT-ATES are therefore indicative and not suitable as a basis for financial decision-making.
Nevertheless, CAPEX and OPEX values are relevant to tools such as the DesignToolkit and MESIDO, which assess the affordability of a heating system using HT-ATES. To provide users with initial guidance, these maps are only shown as a general indication. Users must enter case-specific values themselves to obtain a more accurate estimate.
The economic model in ThermoGIS-HT-ATES is based on a net present value model (discounted cash flow) that has also been used for ThermoGIS geothermal. The NPV model has not been specifically adapted for HT-ATES, only input was changed. As a result, certain costs, such as the required pump energy, may be incorrectly estimated. In HT-ATES, for example, only one pump is usually in operation at a time, whereas in geothermal energy, both the ESP and the injection pump run simultaneously.
The OPEX is divided into:

- Fixed costs: partly a fixed amount per year (fixed OPEX, €), partly dependent on the size of the installation (variable OPEX, €/kW).
- Variable costs: dependent on the amount of energy produced (€/kWh).

The input values used are shown in Table 2, with an explanation in Vrijlandt et al. (2023). Table 1 shows the units used in the economic maps.

Table 2 Economic maps, incl. units.

Map	Unit
capex	M€
opex	M€ (OPEX in first year)
fixedopex	M€ (over total lifetime: 30 year)
varopex	M€ (over total lifetime: 30 year)
utc	€ct/kWh

1.2.6. Technical and economic input parameters

Tables 3 and 4 show the technical and economic constant values used to create the HT-ATES potential maps for the Maassluis and Oosterhout Fm.

Table 3 Technical parameters used in HT-ATES potential maps Maassluis and Oosterhout Fm.

Technical parameters	Value	Unit
aquifer top depth	from map REGIS II v2.2	m
aquifer thickness	from map REGIS II v2.2	m
aquifer net-to-gross	from map REGIS II v2.2	-
aquifer permeability	from map REGIS II v2.2	mDarcy
aquifer temperature	from 3D model ThermoGIS	°C
aquifer water salinity	salinity water [ppm] = 70000/1500 × depth [m]	ppm
aquifer anisotropy	8	-
injection temperature hot well	80	°C
cut-off temperature (minimal production temperature in hot well)	45	°C

injection temperature cold well (retour temperature heating network)	40	°C
injection/production period (max. 182 days)*	120	day
ROSIM simulation time (constant capacity after x years)	15	year
minimum depth**	100	m
maximum depth**	500	m
filter fraction (% from aquifer thickness)	25	-
kh cutoff **	1	Darcy
filter length (% of total aquifer thickness)	0.9	-
specific clogging verlocity (Vv)	0.3	m/year
Membrane Filter Index (MFI)	0.1	s/l2
depth factor	0.01 (depth correction from 100m)	-
distance between two wells at reservoir level	2x thermal radius	m
outer diameter (open production interval)	31	inch
pump depth	150	m
put segment length	30	m

* when the number of production days is <20, the simulation stops
** for faster calculation

Table 4 Economic parameters used in HT-ATES potential maps Maassluis and Oosterhout Fm.

Economic parameters	Value	Unit
economic lifetime	30	year
drilling time	1	year
well costs	100.000 + 1000*depth + 0.3*depth^2	M€
CAPEX base costs (excl. wells)	1.1	M€
CAPEX variable costs (excl. wells)	25	€/kW
CAPEX contingency	25	%
annual OPEX base costs	70000	€
annual OPEX per unit power	6.8	€/kW
annual OPEX per unit produced energy	0	€ct/kWh
electricity purchase price for operations	8	€ct/kWh
tax rate	25	%
interest on loan	5	%
inflation	2	%
required return on equity	7	%
debt ratio	80	%