OPTIMISED INTEGRATION OF THERMAL AQUIFER STORAGE IN DISTRICT HEATING SYSTEMS – ATES-POTENTIALS IN GERMANY

OptInAquiFer: Optimierte Integration von thermischen Aquiferspeichern in Fernwärmenetze

CONTENT

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RESEARCH PROJECT „OPTINAQUIFER“

- SHORT INTRODUCTION OF THE PROJECT AND SUB-PROJECTS -

Geology

GTN

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Storage Systems

HAMBURG INSTITUT

Storages in District Heating

Öko-Institut e.V.

Is seasonal heat storage in an aquifer feasible from a geological and technical perspective?

- Are there storage formations?
- Are they suitable for storage?

Which concepts are economically feasible?

- High-temperature application >70°C
- Integration of storage via heat pumps and power storage (TTES)
- Design of reheating/ booster for very high availability (Supply Temperature)

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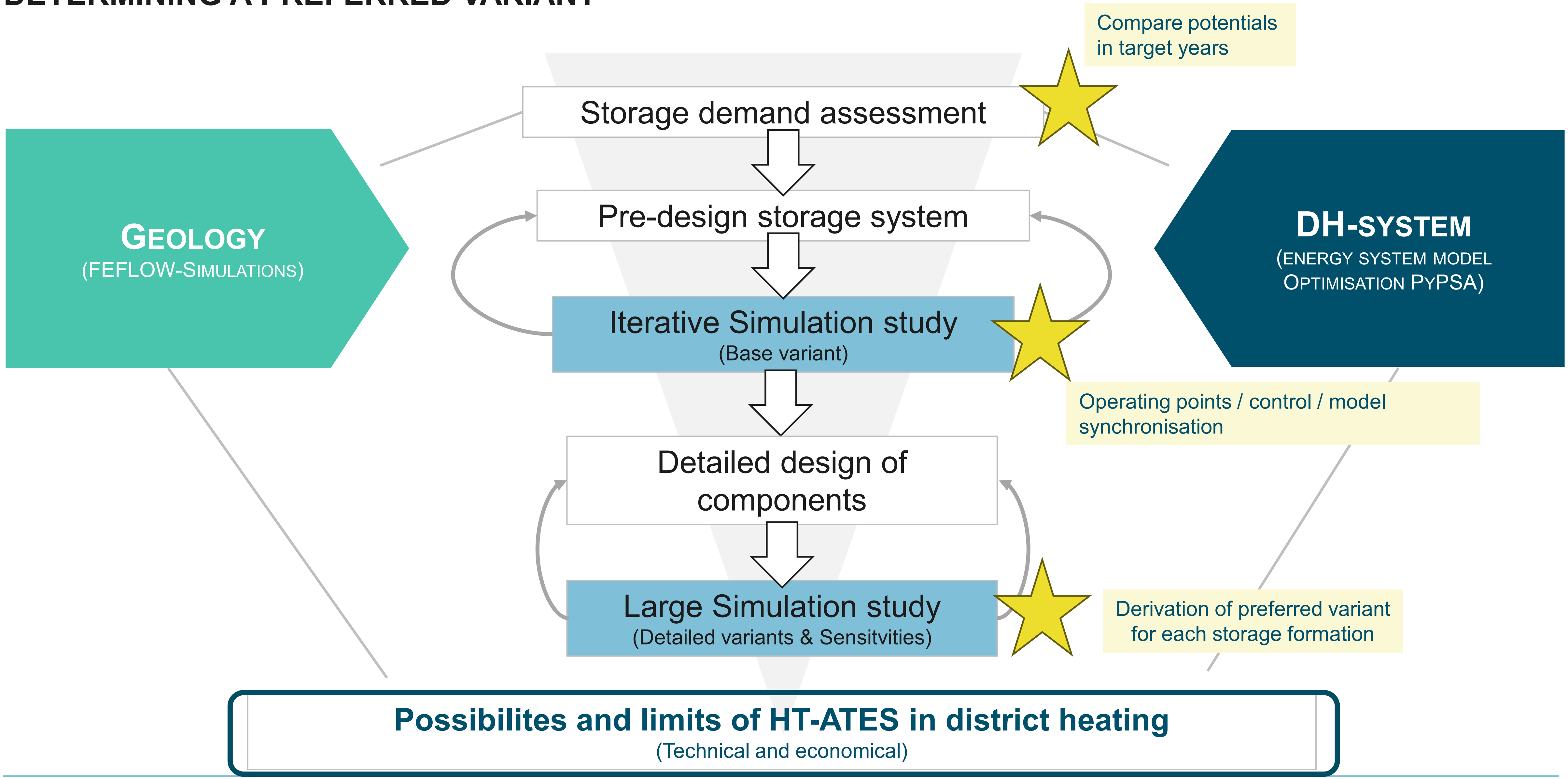
DETERMINING A PREFERRED VARIANT



KEY QUESTIONS TO BE ANSWERED

- What is the **technical potential** of HT-ATES for seasonal energy storage in different **DH types**?
- What is the **spatial distribution** of HT-ATES potential in the North German Basin (NGB), Upper Rhine Graben (URG) and Molasse Basin (MB)?
- What is the potential **heat demand** (per DH type) and **available heat** supply to be stored in HT-ATES?

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MAIN STEPS AND SOURCES

Data collection

- Current and potential DH areas
- Geothermal conditions
- Renewable and waste heat potentials

Data processing

- Comparison of different sources
- Categorization of DH areas
- Processing in QGIS (matching, clipping, intersecting…)

Results

- Generating and interpreting results
- Conclusions and need for further research

MAIN STEPS AND SOURCES

Main source: Manz et al. (2024): Spatial analysis of renewable and excess heat potentials for climate-neutral district heating in Europe

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MAIN STEPS AND SOURCES

Main sources:
NGB: Frick et al.(2022), (Obst & Wolfgramm, 2007)
URV: LGRB et al. (2013); Freymark et al. (2020)
MB: Beichel et al. (2014); Bohnsack et al. (2020); Füchtbauer (1964); Homuth et al. (2014); Kronmüller & Kronmüller (1987); Bayerisches Landesamt für Umwelt [BLfU] (2025)

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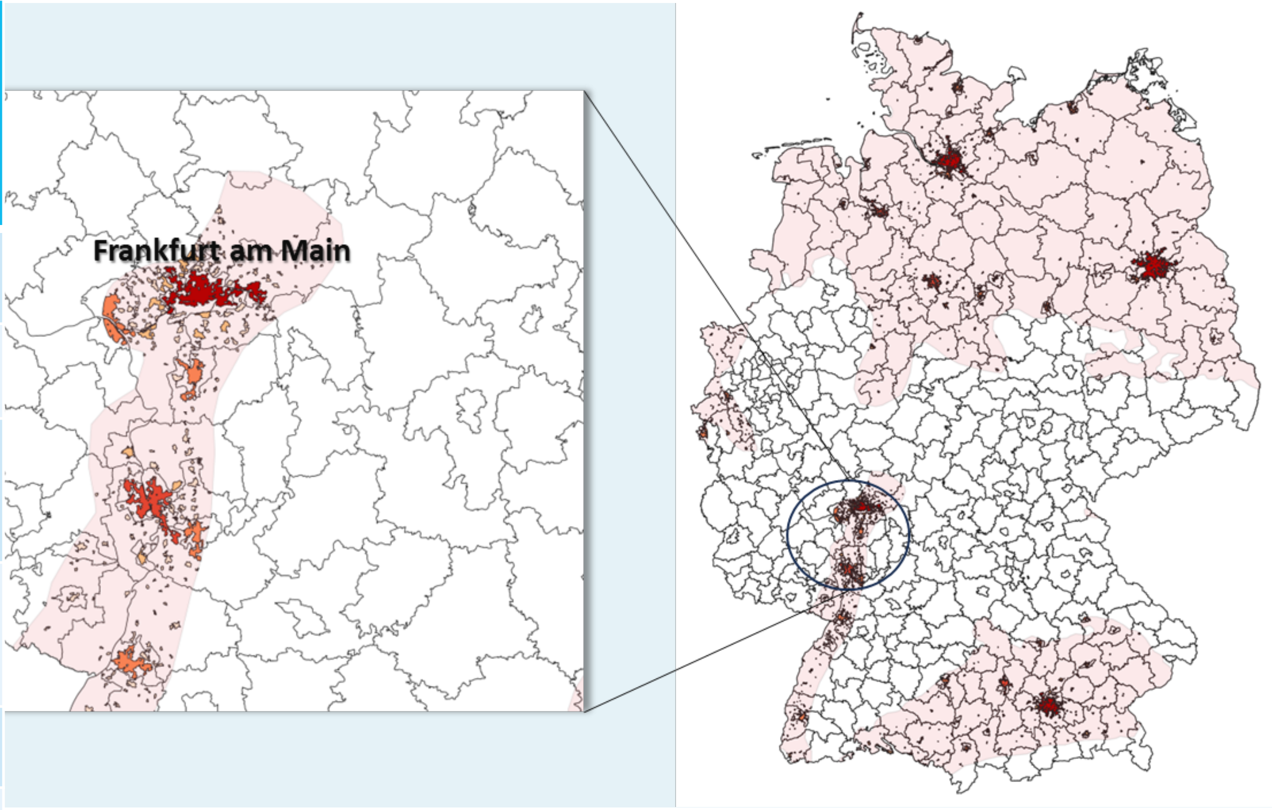
CURRENT AND POTENTIAL DH-AREAS IN GERMANY IN GEOTHERMAL REAGIONS

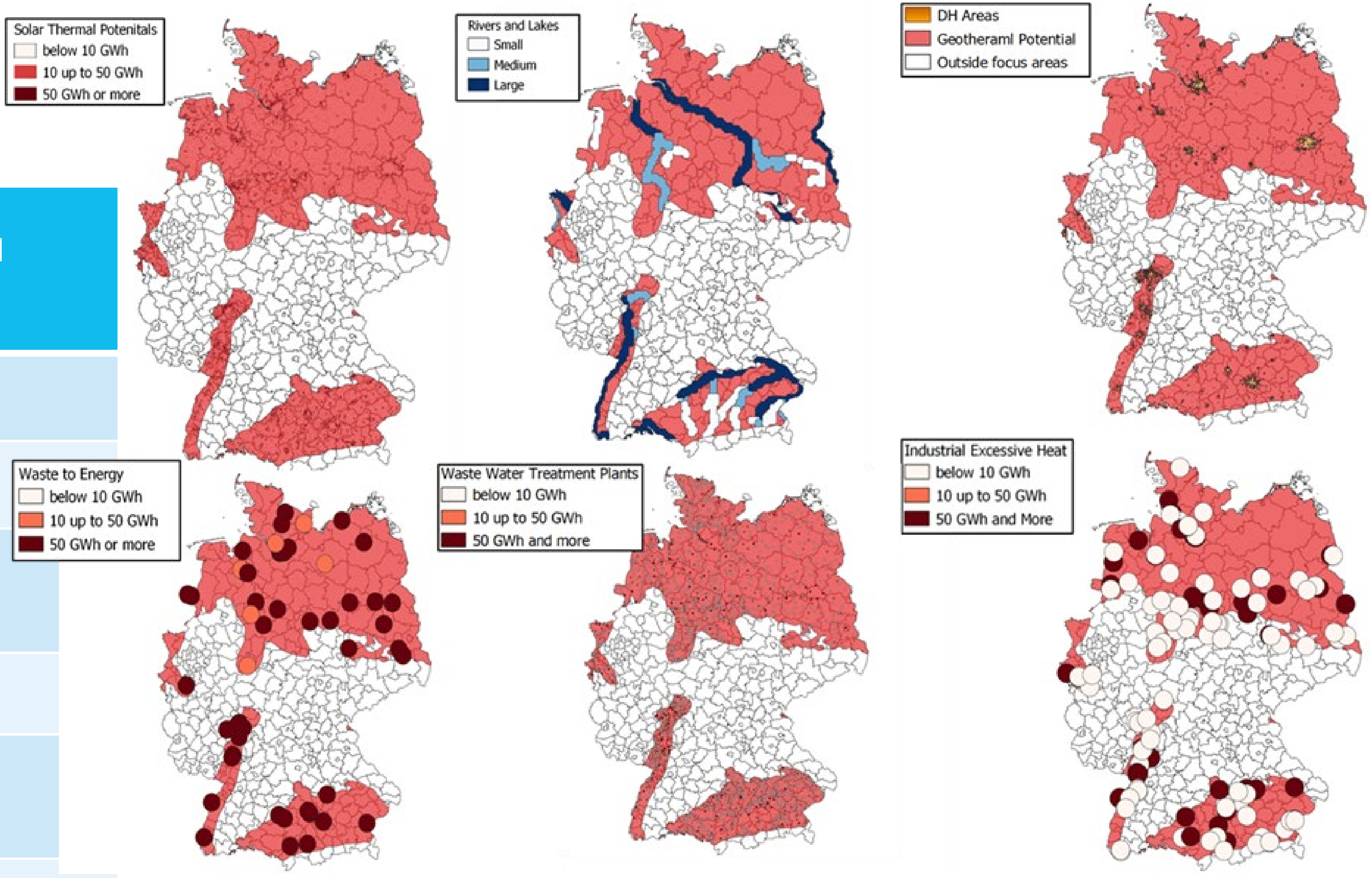
Type	Size [GWh/a]	Number	Heat supplied by DH [GWh/a]	Average heat demand per DH-system [GWh/a]
5: very large	>3,000	4	30,250	7,562
4: large	1.000-3,000	8	13,423	1,678
3: medium-large	250-1,000	21	11,568	550
2: medium-small	100-250	45	6,558	145
1: small	<100	495	12,480	25
Total		**573**	**74,278**	



RENEWABLE AND WASTE HEAT POTENTIAL FOR DH IN GERMANY

- Considered Renewable heat potentials:

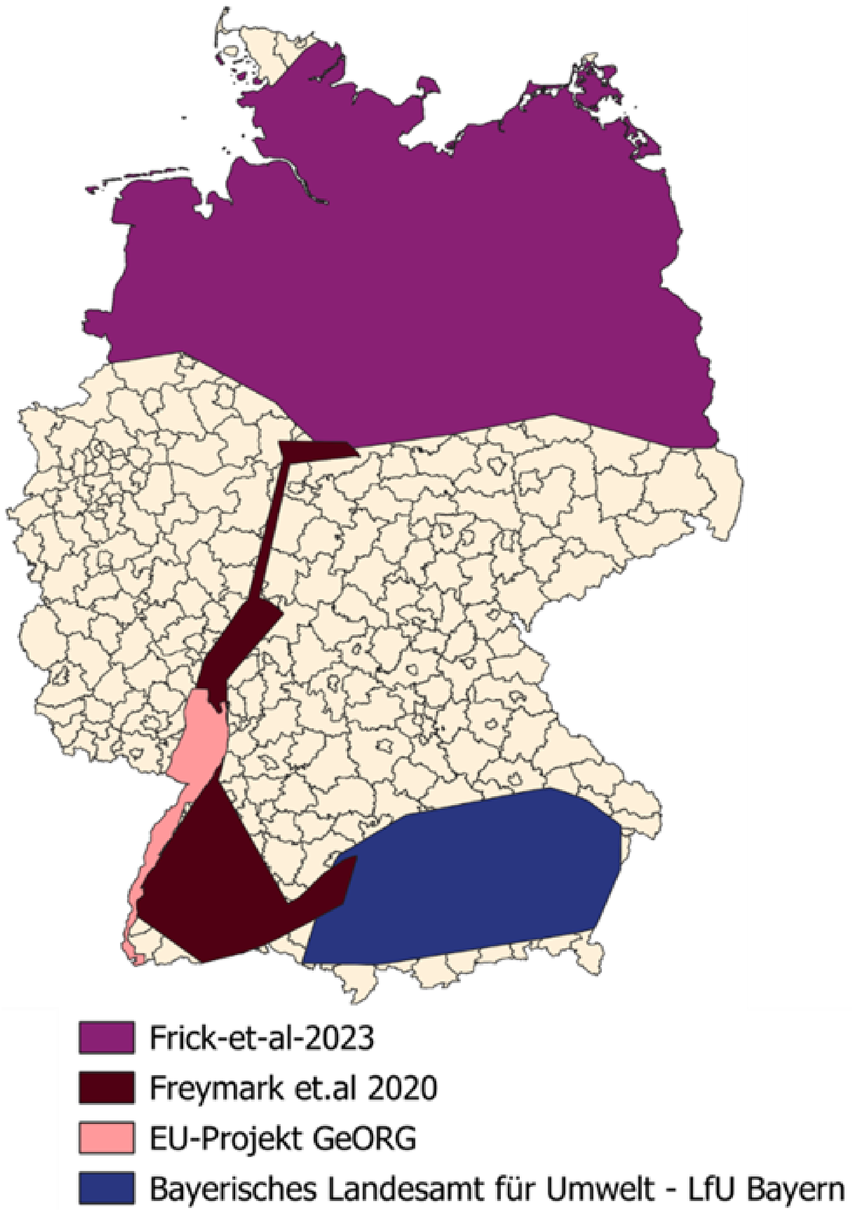
	Max. Distance to DH system [km]	Overall technical potential [GWh/a]
Large Solar Thermal	0.2	17,024
Rivers and lakes	5	275,327
Hydrothermal energy (deep geothermal)	15	407,816
Waste to Energy	20	166,000
Waste water treatment plants	2	23,480
Industrial waste heat	20	15,327



GEOTHERMAL/ ATES CONDITIONS

Main parameters:

- Temperature (T)
- Depth
- Water density (C), Rock density (ρ) and porosity (Φ)
- Reservoir Thickness (H)
- Effective reservoir volume (V_A)
- Specific heat capacity (C_A)
- Packing Correction Factor (F_p)
- Recovery factor (F_r)



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GEOTHERMAL/ ATES CONDITIONS – MAIN PARAMETERS

Parameter	Description	Data Source
Temperature (T)	Heat distributed at different depths.	3D thermal models (e.g. CEBS, GeotIS, regional thermal datasets) and boreholes data.
Depth	Focusing on medium deep high temperature storage from 500 to 1500 m.b.s.	3D Geological Models.
Water density (C), Rock density (ρ) and porosity (Φ)	Relative pore volume fraction of the reservoir rock.	Average values from literatures.
Reservoir Thickness (H)	The vertical thickness of the geological layer that could be used for storing or extracting heat (10-20 m).	3D Geological Model, Seismic and borehole correlation and Facies and lithological models.
Effective reservoir volume (V_A)	Volume of usable reservoir for heat extraction/storage.	Calculated based on geological model data.
Specific heat capacity (C_A)	The amount of heat that could be stored in the reservoir.	Calculated based on water, rock density and porosity.
Packing Correction Factor (F_p)	Accounts for spacing of thermal wells to avoid overlap in ATES.	Assumption based on heat interference between adjacent wells (Frick et al., 2022).
Recovery factor (F_r)	Accounts for energy losses during heat extraction.	Observed from well-designed high-temperature ATES system (Frick et al., 2022).

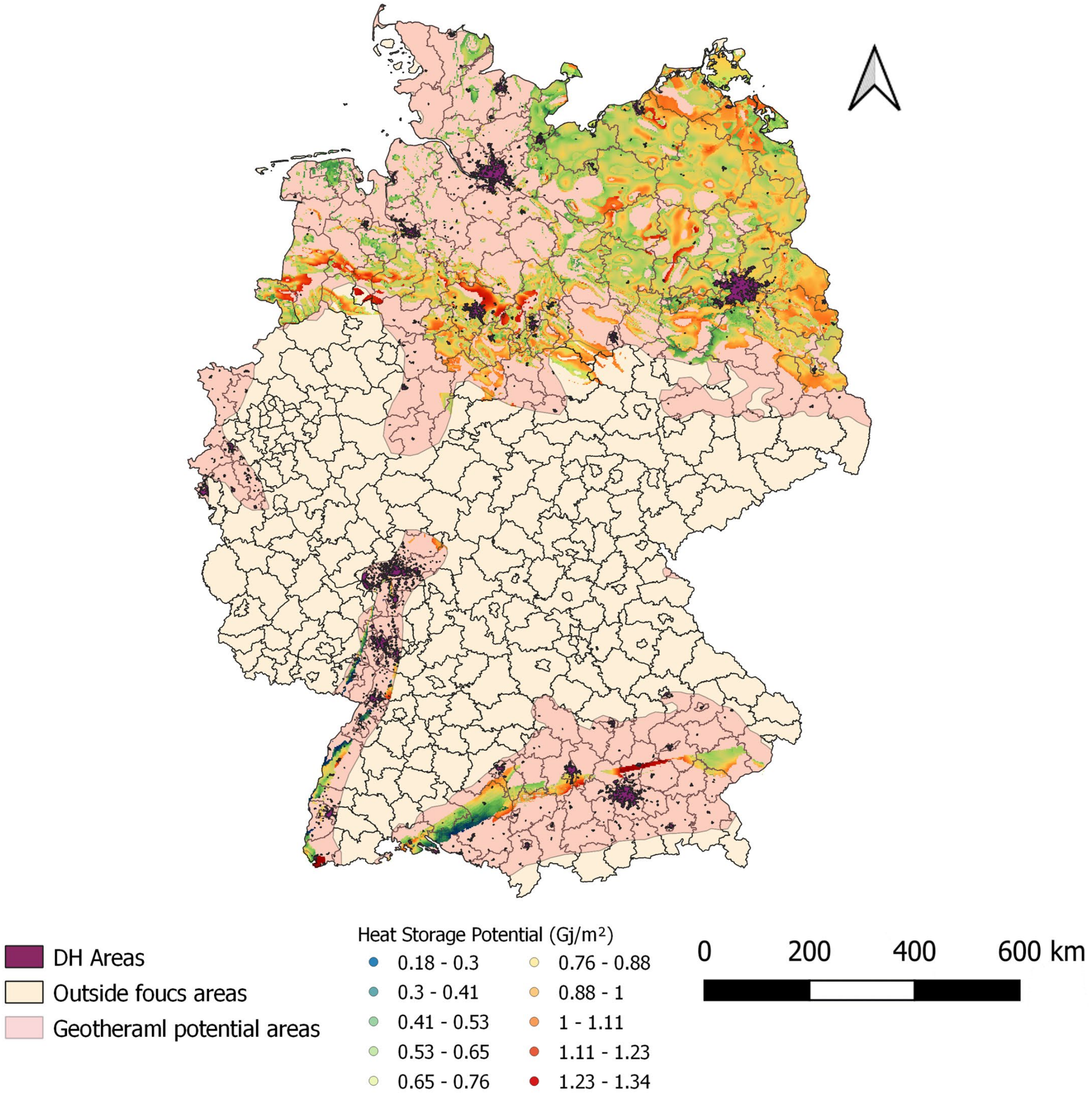
POTENTIALS IN GERMANY

DH systems:

- 573 potential DH areas (130 in South-German Molasse Basin, 260 in North German Bassin, 183 in Upper Rhine Valley)
- For 424 DH systems sufficient data, in 167 DH systems potential identified (in 162 enough data available for assessment)

Potential:

- Total storage potential approx. 706 TWh
- 19 TWh in South-German Molasse Basin, 550 TWh in North German Bassin, 136 TWh in Upper Rhine Valley
- Potentials / possible application in small DH systems (Type 1 and 2) due to low amount of heat supplied to final customers questionable



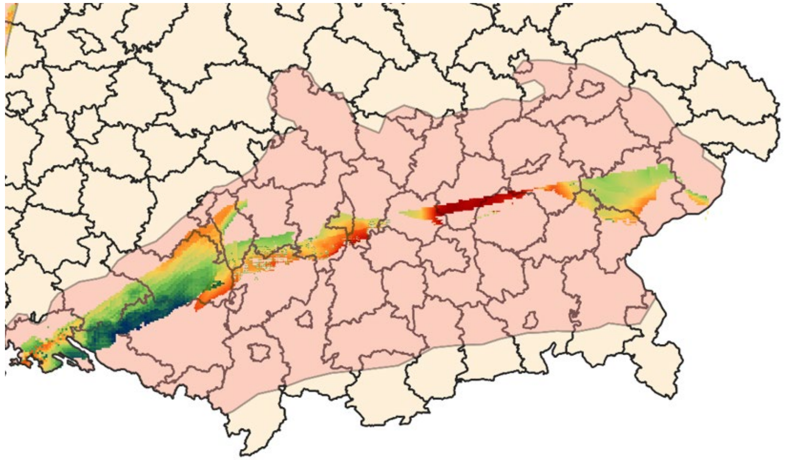
POTENTIALS IN GERMANY – SOUTH-GERMAN MOLASSE BASIN

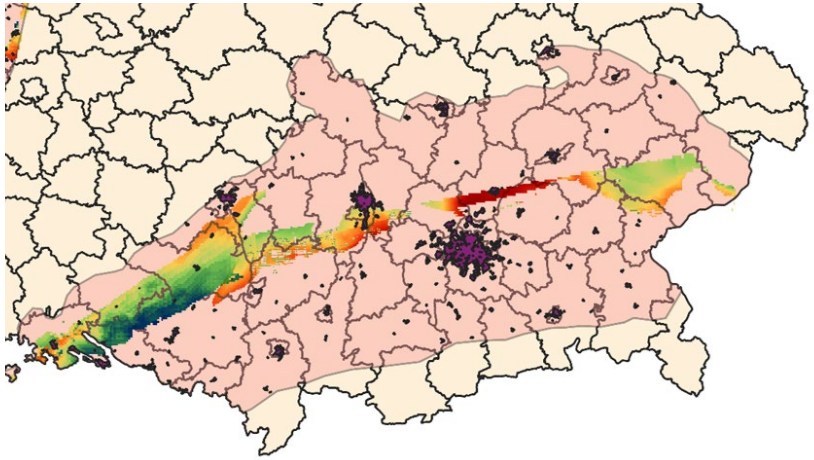
DH systems:

- Total: 130
- Sufficient data: 108
- Potential in 21 DH systems, enough data in 19 DH systems

Potential:

Type	Number	Heat supply DH [TWh/a]	HSP [TWh/a]	Available heat for storage [TWh/a]
5	-	-	-	-
4	1	1.3	1.0	1.4
3	1	0.6	0.2	1.5
2	1	0.2	6.2	0.2
1	16	0.3	8.4	12.3
Total	**19**	**2.4**	**15.8**	**15.4**





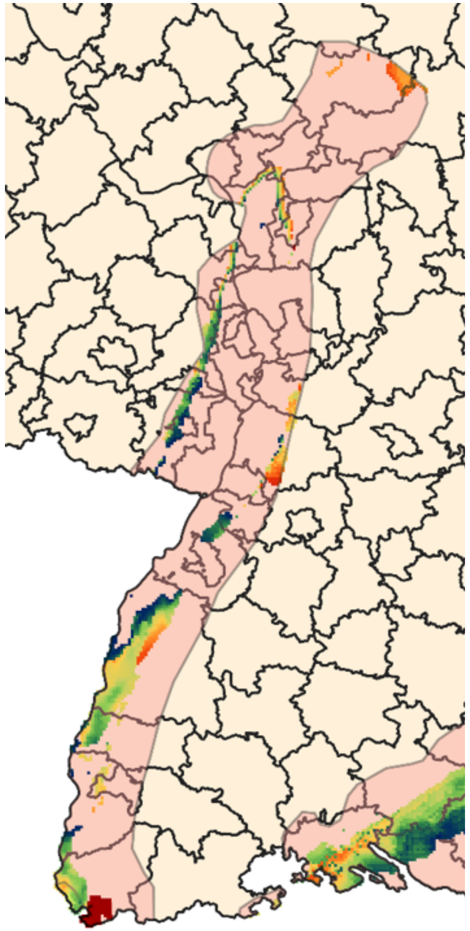
POTENTIALS IN GERMANY – UPPER-RHINE VALLEY

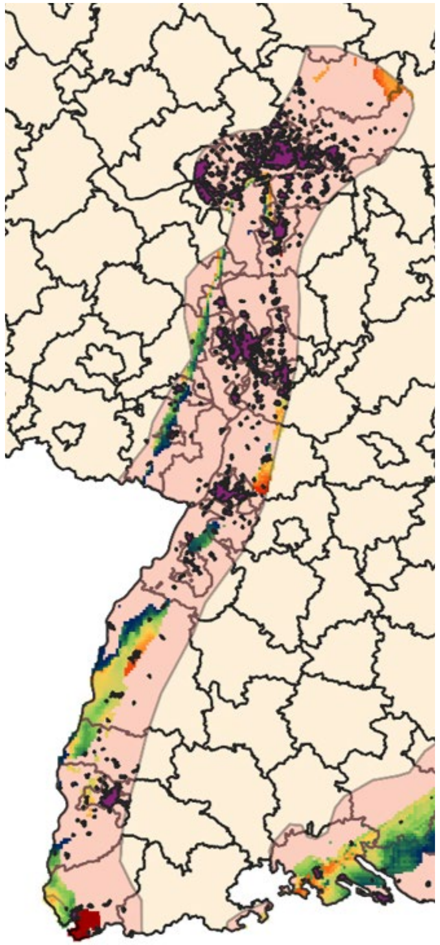
DH systems:

- Total: 183
- Sufficient data: 87
- Potential in 37 DH systems, enough data in 34 DH systems

Potential:

Type	Number	Heat supply DH [TWh/a]	HSP [TWh/a]	Available heat for storage [TWh/a]
5	1	3.9	1.3	7.9
4	1	1.0	0.6	4.7
3	1	0.7	1.0	4.0
2	2	0.3	120.2	3.4
1	29	0.9	8.6	50.1
Total	**34**	**6.8**	**131.8**	**70.1**





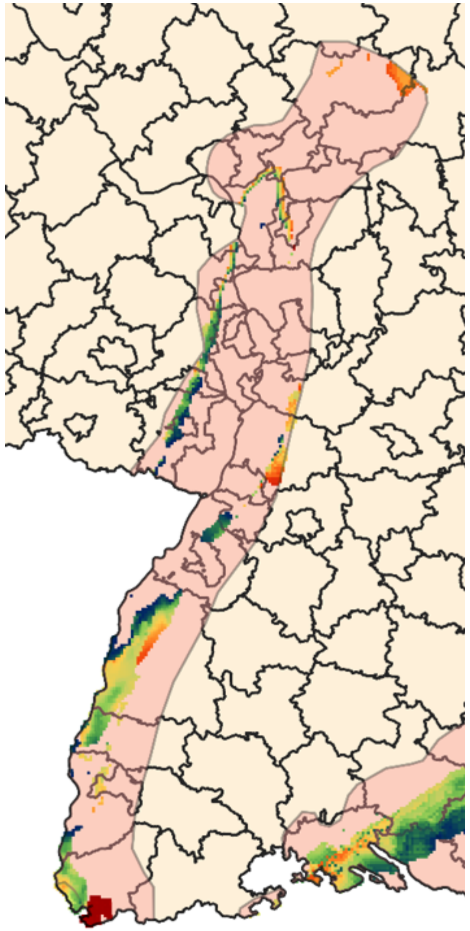
POTENTIALS IN GERMANY – NORTH GERMAN BASIN

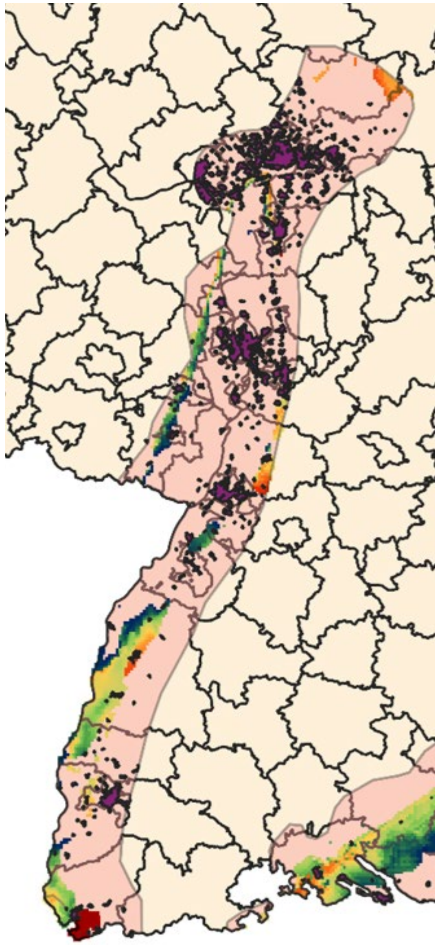
DH systems:

- Total: 260
- Sufficient data: 229
- Potential in 109 DH systems, enough data in 109 DH systems

Potential:

Type	Number	Heat supply DH [TWh/a]	HSP [TWh/a]	Available heat for storage [TWh/a]
5	2	19.8	215.0	13.7
4	2	4.3	85.3	5.3
3	9	4.4	112.7	10.8
2	9	1.3	48.3	6.7
1	87	2.2	89.1	70.4
Total	**109**	**32.0**	**550.4**	**106.9**



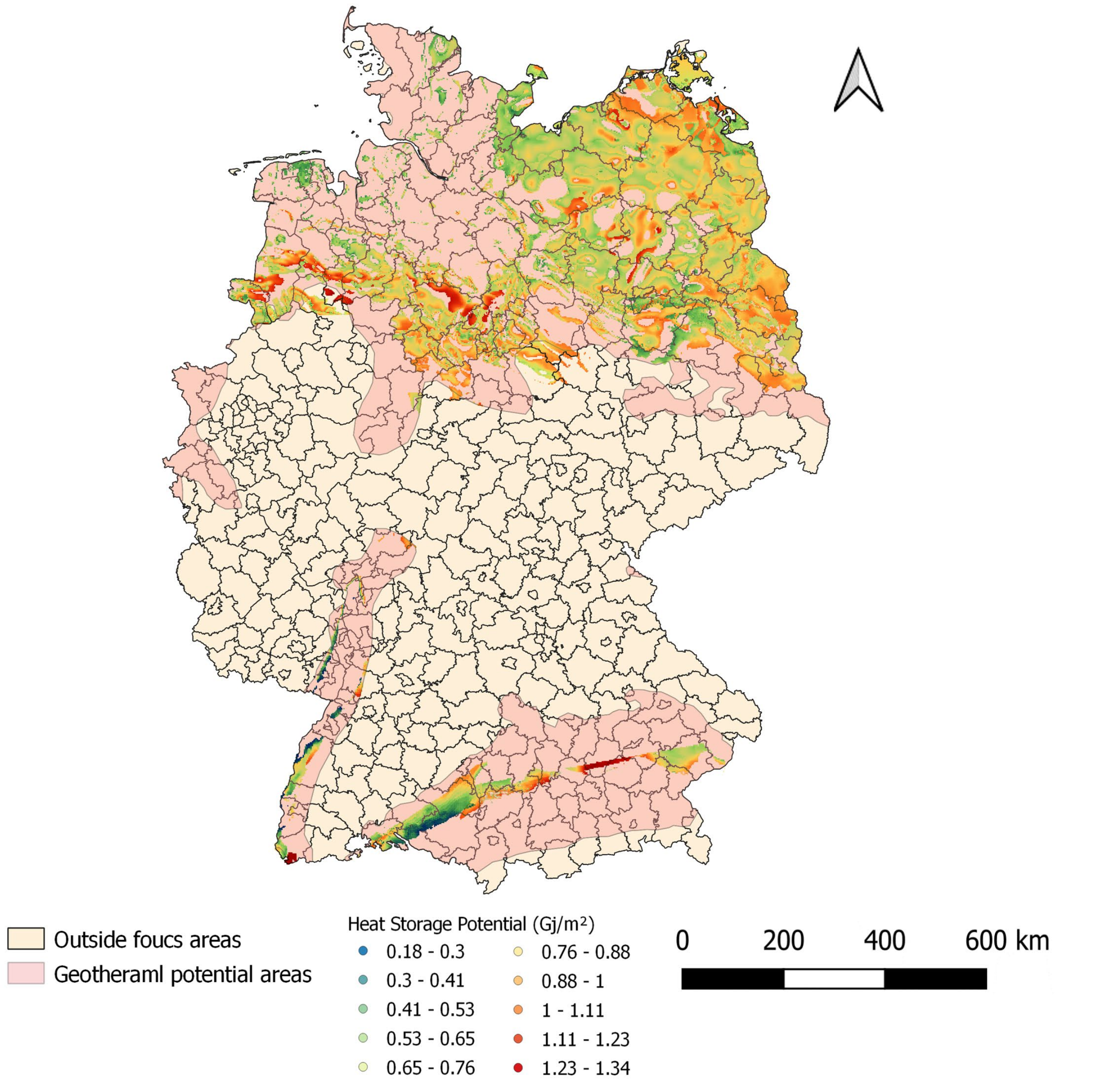


POTENTIALS IN GERMANY – SUMMARY

Key findings:

- ATES only a **technology for larger systems** (type 4 and 5, probably also type 3)
- Match of all **relevant requirements for ATES** deployment only in a few DH systems with a sufficient size: only 18 identified
- Highest potential expected in **North German Basin**
  - In the other geothermal regions, in only a few DH systems high HSP + high renewable and waste heat potential + high heat demand

➢ Results still need to be handled with care: **data available** for the German underground is still limited and therefore the **uncertainties are high** → “it’s dark in front of the hoe”: you need to drill to know if the expected potential is real!



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GENERAL TAKE-AWAYS

An ATES as Stand-Alone-Solution cannot meet urban network requirements

High power

High Temperature

High Capacity

With the right design, reheating via one or more heat pump(s) offers multiple advantages

Fully-fledged generator

Increase of storage efficiency

Customised technology combinations are required for district heating to optimise system benefits

Combination of capacity and power

Peak load capability

Note: a handbook for the development of LTES in Germany will be published in 1st quarter 2026 by BfEE

Thank you very much for your attention!

Please don‘t hesitate to reach out to us: b.koehler@oeko.de

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Responsibility for the content of this publication lies with the authors.

MAIN SOURCES GEOTHERMAL CONDITIONS

Region	
NGB	Obst & Wolfgramm (2007): Frick et al. (2023):
URG	(LGRB et al., 2013): Regierungspräsidium Freiburg – Landesamt für Geologie, Rohstoffe und Bergbau, Landesamt für Geologie und Bergbau Rheinland-Pfalz, BRGM Siège, BRGM Centre scientifique et technique, & Departement Umweltwissenschaften Universität Basel – Angewandte und Umweltgeologie. (2013). Geodaten des EU-Projekts GeORG. Daten bereitgestellt durch das Regierungspräsidium Freiburg – Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) am 20.03.2025. https://www.geopotenziale.eu Freymark, J.; Bott, J.; Scheck-Wenderoth, M.; Bär, K.; Stiller, M.; Fritsche, J.-G.; Kracht, M.; Gomez, L. (2020): 3D-URG: 3D gravity constrained structural model of the Upper Rhine Graben. https://doi.org/10.5880/gfz.4.5.2020.004
MB	Beichel et al. (2014): Beichel, K., Koch, R., & Wolfgramm, M [M.] (2014). Die Analyse von Spülproben zur Lokalisierung von Zuflusszonen in Geothermiebohrungen. Beispiel der Bohrungen Gt Unterhaching 1/1a und 2. (Süddeutschland, Molassebecken, Malm). Geologische Blätter(64 (1-4)), 43–65. Bohnsack et al. (2020): Bohnsack, D.; Potten, M.; Pfrang, D.; Wolpert, P.; Zosseder, K. (2020). Porosity–permeability relationship derived from Upper Jurassic carbonate rock cores to assess the regional hydraulic matrix properties of the Malm reservoir in the South German Molasse Basin. Geothermal Energy, 8(1). https://doi.org/10.1186/s40517-020-00166-9 Füchtbauer, H. (1964): Sedimentpetrographie der älteren Molasse nördlich der Alpen. Eclogae Geologicae Helvetiae(57), 156–298 (Habilitationsschrift). Homuth et al. (2014): Homuth, S., Götz, A. E., & Sass, I. (2014). Lithofacies and depth dependency of thermo- and petrophysical rock parameters of the Upper Jurassic geothermal carbonate reservoirs of the Molasse Basin<BR. Zeitschrift Der Deutschen Gesellschaft Für Geowissenschaften, 165(3), 469–486. https://doi.org/10.1127/1860-1804/2014/0074 Kronmüller, R. & Kronmüller, K. (1987): Die Bausteinschichten - Sedimentologie und Diagenese eines Speichergesteins. Erdöl-Erdgas-Kohle(103), 61–66. Bayerisches Landesamt für Umwelt [BLfU] (2025): Geodaten des EU-Projekts GeoMol: Daten bereitgestellt durch das Bayerische Landesamt für Umwelt (BLfU) am 20.2.2025. https://www.3dportal.lfu.bayern.de/?view=7ac8269e-dde9-11ed-a73f-77e5adaeab39