Interreg North-West Europe DGE-ROLLOUT

New Horizons, More Potential

Action plan

Deliverable WP LT 3.3

Gabriela Gonzalez (GD NRW)

Anna Thiel (GD NRW)

September 2022

Contents

1 Introduction

This action plan is a checklist for what next steps after the Deep Geothermal Energy Rollout (DGE-Rollout) project timeframe are planned in order to reach the long-term goals fostering the expansion of deep geothermal energy as climate friendly energy resource in North West Europe.

The action plan was developed on the basis of the deliverable WP LT D. 3.3 New horizons, more potential.

Workpackage	Activity nr	Deliverable nr	Title	Target value	End month
WP Long Term	Activity 3	Deliverable 3.3	New horizons, more potential	1.00	Oct-2022
Implementation of an action plan to structure further subsurface mapping campaigns for new promising aquifer horizons (e.g. deeper limestone reservoirs). This will reveal further potential that hasn't taken into account jet and increase the DGE potential.					

The present report is structured as follows, a general status of the available subsurface information in Germany, Belgium, France, and the Netherlands in the areas part of the DGE-Rollout, the deep geothermal projects with status and how the lack of information is identified and measured. The next topic is the prioritization of subsurface campaigns and existing programs dedicated to acquire new data in regional level with the table action plan. Finally, the evaluation of the progress, it is a point of view of how the current subsurface mappings impact the development of the current and new geothermal projects.

2 Aim of the action plan

The aim of the action plan is to summarize the structure for further subsurface mapping campaigns for new promising aquifer horizons (e.g. deeper limestone reservoirs). Through the analysis of the available information related to the geothermal mapping in the different countries part of the project, new targets horizons with that hasn't been considered yet and increase the DGE potential.

3 Introduction

The geothermal exploration process starts in a regional level, it becomes local and gets more detailed with the development of a project. It is illustrated in Figure 1, the decision-making factors from the societal-technical and geologic-technical aspects, (Moeck, et al., 2020). The bottom triangle is related

to the subsurface analysis. The understanding of the geological setting using regional information give as a result for the geosystem. A play consists of defined stratigraphic units with the characteristic before mentioned. The prospects are a subdivision of a geothermal play which share common geological controls.

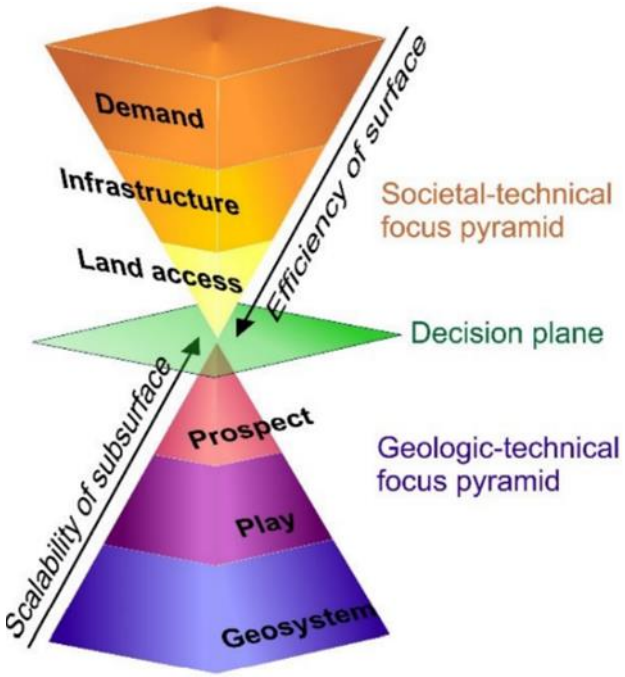


Figure 1 Decision-making factors to start a geothermal project, (Moeck, et al., 2020).

The target horizons with geothermal potential are selected based on the possibility to fulfil all the elements of a geothermal reservoir. In this case, the selected geothermal type is hydrothermal. In Table 1, each parameter and decisive characteristics are described.

Table 1 Main characteristics and parameters in hydrothermal reservoirs system

Reservoir elements	**Characteristics**	**Function**
Top rock	Non-permeable rock	Serve as seal to keep fluids inside a volume
Host rock	Porosity Permeability Thermal conductivity	This rock contains the fluid that will be produce, the most important properties are mention.
Aquifer	Fluid rate Recharge	It is the medium for the energy transport. Its existence is not enough, it has to be sufficient to ensure the viability of the project.
Fault system	Connected	It could increase the drainage area or facility the recharge of the aquifer.
Heat source	High geothermal gradient Deep system	The heat of the source is transferred to the aquifer.

Carbonates and sandstones are the lithologies with the best quality according to the rock characteristics of the host rock. Table 2 summarize the horizons with proved or expected geothermal potential described in the literature. In general, the lithology corresponds to sandstone and limestones with exception of the basement in the Upper Rhine Graben. The letter refers to the country: Belgium (B), France (F), Germany(G) and the Netherlands (N). The horizons are enclosed by series and classified as regional when located in the 4 countries of the DGE-Rollout project or local when distributed in 3 or less countries.

Table 2 Geothermal target horizons in North West Europe. The letter refers to the country: Belgium (B), France (F), Germany(G) and the Netherlands (N).

Geologic Era	System/ Period	Series/ Epoch	Geothermal horizon		Regional names	Lithology
			Regional	Local		
Cenozoic	Quaternary	Holocene				
		Pleistocene				
	Neogene	Pliocene				
		Miocene				
	Paleogene	Oligocene		F, G, N	G (URG) – Niederrödern, Froidefontaine	Sandstones
		Eocene		F, G, N	G, N- Dongen N- Brussels Sand Member G(URG) - Pechelbronn	Sandstones
		Paleocene				
Mesozoic	Cretaceous	Upper/Late		G, N	N- Chalk	Carbonates
		Lower/Early		G, N	N- Rjngland	Sandstones
	Jurassic	Upper/Late		G, N	N- Schieland	Limestones (G-URG) Sandstones
		Middle		G, F	G (URG)- Hauptrogenstein	Carbonates
		Lower/Early				
	Triassic	Upper/Late		B, N	F, G- Keuper	Sandstones
		Middle	B, F, G, N		G- Muschelkalk	
		Lower/Early		F, G, N	G, N, F- Bundsandstein	Sandstones
Paleozoic	Permian	Upper/Late			G, N- Zechstein	Carbonates
		Middle		B, G, N	G, N- Rotliegend	Sandstones
		Lower/Early		G, N	G, N- Rotliegend G (URG) – Permo-Carboniferous	Sandstones
	Carboniferous	Upper/Late		G, N	G- Namurian N- Limburg	Sandstones G (URG) – Crystalline Basement

		Lower/Early	B, F, G, N		G- Dinantian or Kohlenkalk N- Zeeland	Carbonates
	Devonian	Upper/Late		G		
		Middle	B, G, N		G- Massenkalk	N- Sandstones G- Carbonates
		Lower/Early		B		Sandstones/ Quartzite

4 Description of data status

In order to describe the status of the projects it is relevant to summarize the available data. In this report the data is divided in analogue to the levels of the pyramid. The regional information of the geosystem is given by the wells and seismic information. The play, which is the system with the stratigraphic units, is related to the existing 3D geological models and finally the prospects are correlated to the current geothermal projects.

The available data between the countries in the DGE-ROLLOUT project is diverse and not possible to compare due to the missing access to the different databases and diverse information status. A general view of the well, seismic, and geological models is given by region, and in the last chapter where, the current geothermal projects of the countries Belgium, France, Germany and The Netherland are integrated.

4.1 Germany, North-Rhine Westphalia

The state is situated in the West part of Germany and has borders with Belgium and Netherlands. The geothermal target horizons based on the geology are Cretaceous, Turonian to Cenomanian series, Permian, the Rotliegend series. In the Carboniferous, the Dinantian or Kohlenkalk formation (Visean to Tournasian series), it is present in Belgium and the Netherlands, and the Devonian, the Massenkalk formation (Frasnium to Givetium series).

1. Wells

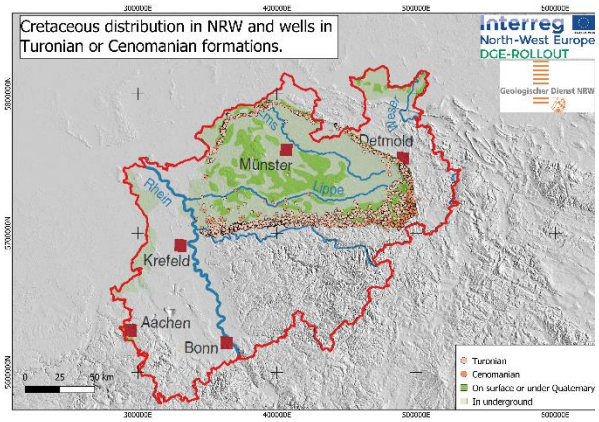
The distribution of the wells is not regular in the state. Its distribution is depending on different factors e.g. could be related to the delimitation of the formation on the surface. In general, the high number of wells in the Cretaceous is due the coal exploitation of the late carboniferous formations in the Ruhr district, which is also related to the data concentration in this area.

The majority of the wells are shallow deep. In the case of the Devonian, 5 wells have reached it deeper than 2,000 m. it means, with a previous column Tertiary, Cretaceous and/or Carboniferous, those are: Münsterland 1 (5956 md), Versmold 1 (5500 md), Isselburg 3 (4398 md), RWTH 1 (2544 md) and Erlenbach 2 (2830 md).

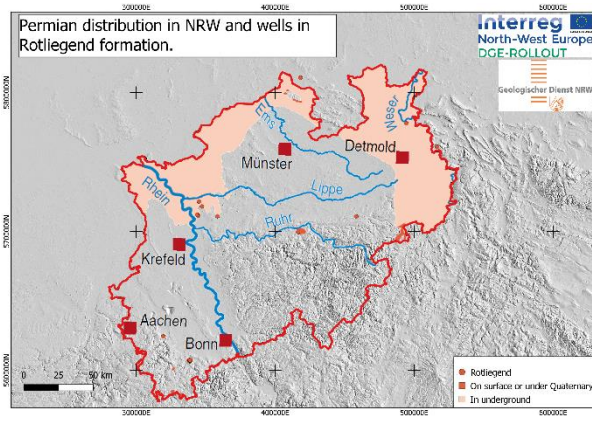
Table 3 Existing well data in NRW related to reach target horizons, unit in number of wells.

	Cretaceous		Permian	Carboniferous		Devonian	
Formation			Rotliegend	Dinantian		Massenkalk	
Series	Turonian	Cenomanian	Rotliegend	Visean	Tournasian	Giventian	Eifelian
Nr. of wells	5118	1895	22	435	157	1831	1917

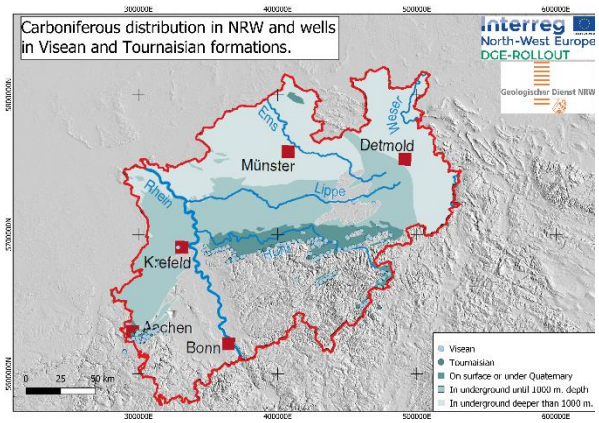
Map 1 Cretaceous period, Map 2 Permian period, Map 3 Carboniferous period and Map 4 Devonian period are giving an impression of how many wells have reached or drilled through different target horizons.



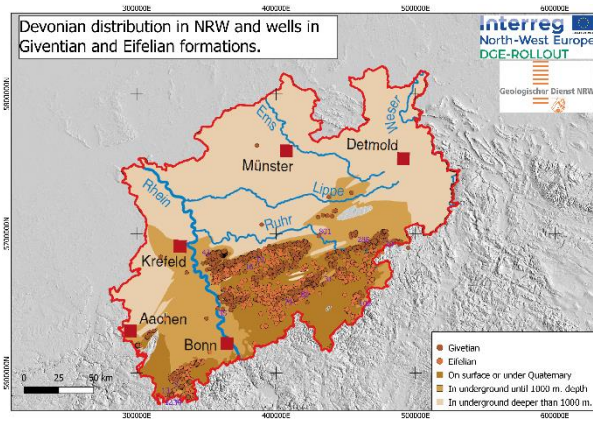
Map 1 Distribution of Cretaceous system in North Rhine-Westphalia and wells in Turonian and Cenomanian series. The dark colors in the distribution are related to the shallow depth the rock is located.



Map 2 Distribution of Permian system in North Rhine-Westphalia and wells in Rotliegend series. The dark colors in the distribution are related to the shallow depth the rock is located.



Map 3 Distribution of Carboniferous system in North Rhine-Westphalia and wells in Visean and Tournaisian series. The dark colors in the distribution are related to the shallow depth the rock is located.



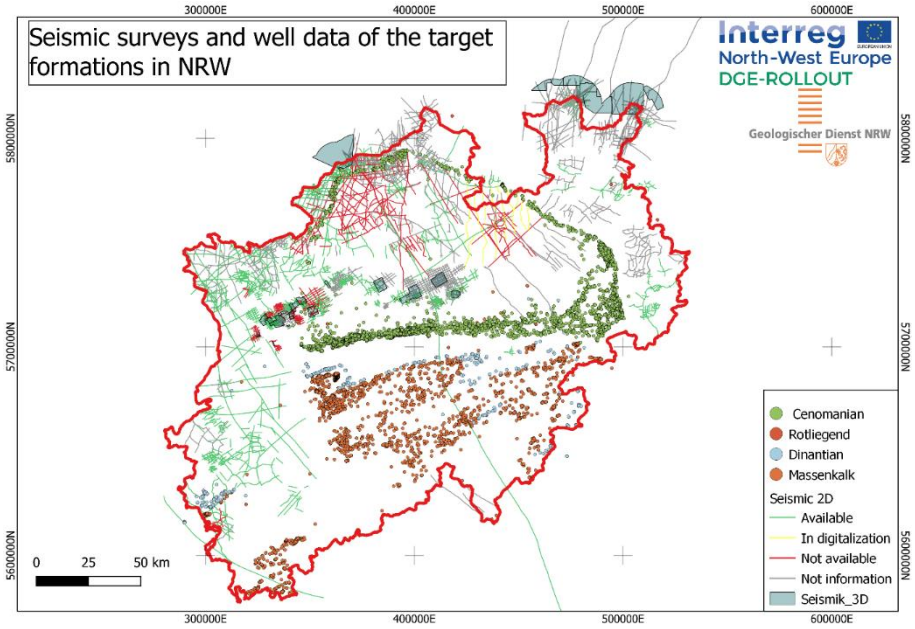
Map 4 Distribution of Devonian system in North Rhine-Westphalia and wells in Giventian and Eifelian series. The dark colors in the distribution are related to the shallow depth the rock is located.

2. Seismic

The majority of the seismic information were acquired in the 50's. The lines from the DEKORP project, a project with the aim to investigate the deep crustal structure of Germany, have the deepest investigation range. Currently, a new seismic campaign es acquired dedicated to geothermal energy, Table 4.

Table 4 Seismic information in NRW

Type of information	General Information					Depth range [km]
	Year	Number	SGY-data	In Time	In Depth	
Lines 2D	1941-1960	1098	40	53	323	0-5
	1961-1980	478	30	147	142	0-3
	1981-2000	232	4	167	132	0-30
	2001-2021	29	-	10	7	
Survey 3D	1985-1990	4				0-3
	1990-1995	5				
	2020	1				0-3



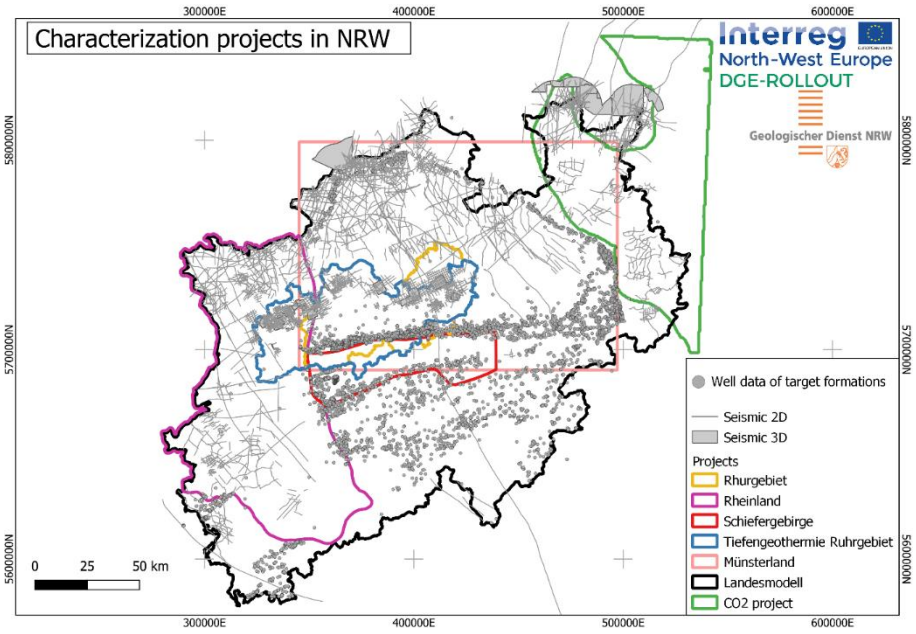
Map 5 Seismic surveys and wells on the target formations.

3. 3D-Models

The geological models available in NRW have been developed with different targets and scales, Table 5. The on-going projects are focusing on the Dinantian and Devonian carbonates mapping for deep geothermal resources.

Table 5 3D geological models in NRW built by the geological survey.

Name of the 3D-Modell		Target Horizon			
		Cenoman-Turon	Rotliegend sandstone	Dinantian carbonates	Devonian Massenkalk
Georesources of the deep subsurface *	Ruhr district			●	●
	Rhineland			●	●
	Rheinisches Schiefergebirge			●	●
Tiefengeothermie Ruhrgebiet				●	
CO2-Projekt			●		
Landesmodell NRW		●	●		●



Map 6 3D geological models of the geological survey of NRW.

4.2 Germany, Upper Rhine Graben

Most of the Upper Rhine Graben (URG) is part of Germany and France, while the southern end also extends into northern Switzerland. The geological units identified as potential geothermal reservoirs based on their favorable thermal and hydrogeological properties are 9, the named tertiary sandstones (Niederrödern, Froidefontaine, and Pechelbronn formations), Mesozoic carbonate formations (Upper Jurassic, Hauptrogesnstein, and Muschelkalk formations), Triassic sandstones (Bundsandstein formation), sandstones and volcanics of the Permo-Carboniferous, and Crystalline Basement (Frey, et al., 2022).

1. Wells

The wells are from oil and gas exploration, exploitation and geothermal wells. By 1989, more than 440 exploration wells and 550 production wells had been drilled in the area, and now more than 15 geothermal deep wells (Frey, et al., 2022) and (Vidal, et al., 2018). Figure 2 shows an extract of the wells in the URG area in the portal GEOTIS.

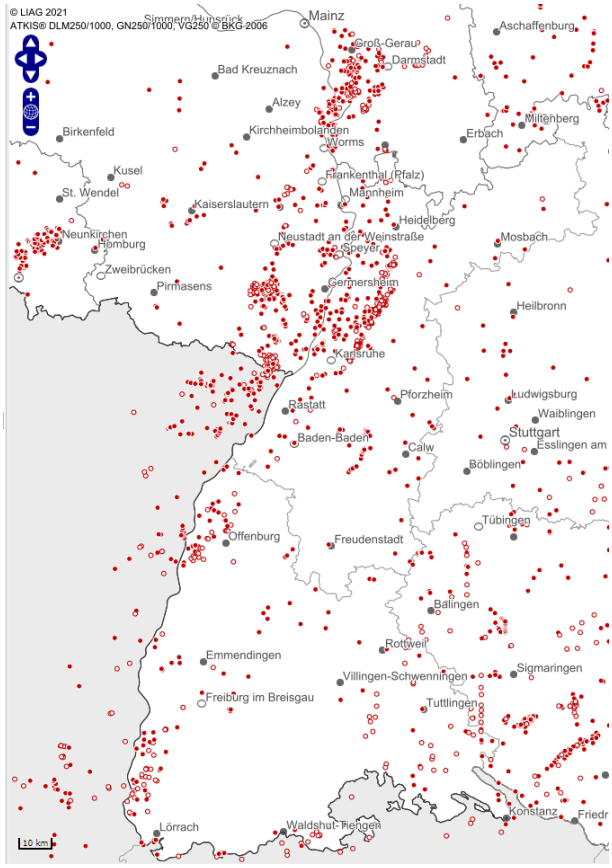


Figure 2 Wells in the Upper Rhine Graben area, extract from GeotIS.

2. Seismic

In the URG the main seismic data is related to the hydrocarbon exploration. It had its peak between the 1950s and 1980s, when mostly 2D seismic profiles where acquired with more than 5,000 km total length, including the lines DEKORP 9N and 9S, which are the deepest lines in the area. New 3D seismic data has been acquired for the development of new projects. InTable 6, the 3D surveys data summarized from Geotis.

Table 6 3D volumes in the URG and main characteristics, summarized from GeotIS.

Survey name	Measuring period	Recording duration
Eich 3D 2009	18.02.2009 - 04.03.2009	6000
Landau 2017	01.01.2017 - 31.12.2017	NA
Mittlerer-Oberrhein-West 2012/2013	06.12.2012 - 08.03.2013	4000
Nördlicher-Oberrhein 2011/2012	20.10.2011 - 28.03.2012	6000
Roemerberg-Nord 2012	03.01.2012 - 02.02.2012	4000
Roemerberg-Suedwest 3D 2011	07.11.2011 - 20.12.2011	4000
Speyer 2005	10.08.2005 - 20.08.2005	5000
Weinheim 2012	03.09.2012 - 18.10.2012	7000
Worms 3D 2009	06.03.2009 - 21.03.2009	6000

The 2D (lines) and 3D data (polygons) are shown in Figure 3. The data older than 5 years should be made available by the state geological services in accordance to the law in Germany related to the geological data.

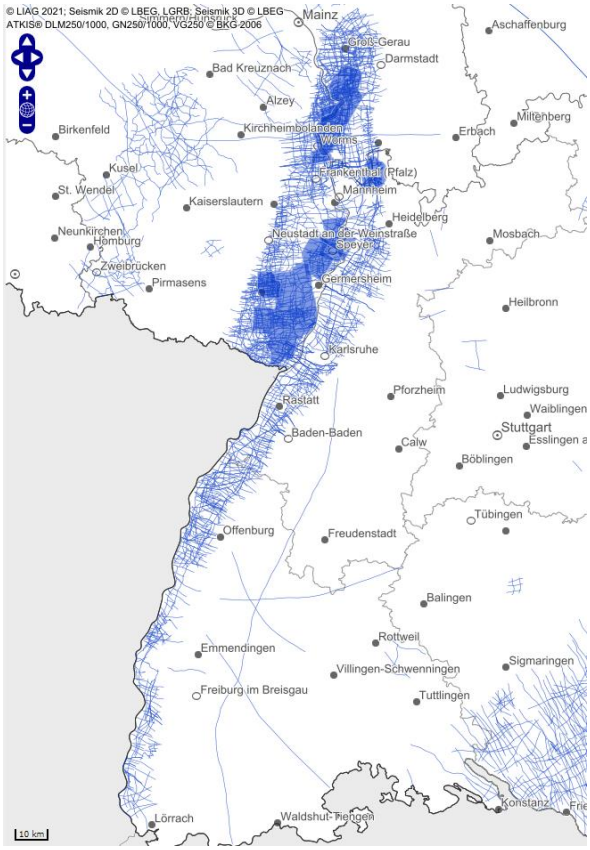


Figure 3 Seismic data in the German area of the Upper Rhine Graben, extract from GeotIS.

3. 3D-Models

Several 3D models of the URG has been built, in reginal and local scale. The purpose has been: calculation of geothermal potential, simulation of ground water flow, uncertainties, etc. The data considered is diverse, the newest models use geophysical data, apart from seismic data like potential methods, to create models with more detail. In the Figure 4 a selection of published 3D geological models is showed. For a brief description the reader is refer to (Frey, et al., 2022).

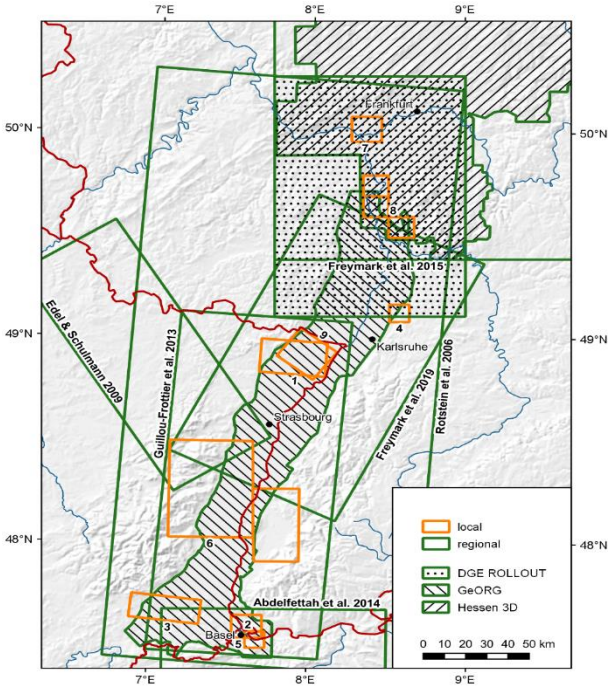


Figure 4 : Selection of published 3D geological models in the URG region. 1 = Dezayes et al. (2011), 2 = Spottke et al. (2005), 3 = Le Carlier de Veslud et al. (2005), 4 & 5 = Meixner et al. (2016), 6 = Bertrand et al. (2005), 7 = Deckert et al. (2017), 8 = Wächter et al. (2018), 9 = Abdelfettah et al. (2020). Note that the Freymark et al. (2020) model area is larger than the map section shown here (Frey, et al., 2022).

The most detailed models in the URG with a regional scale are mention in Table 7, with the target and a general description of it.

Table 7 Geological models of the URG and the characterized reservoirs.

Name of the 3D-Model	Target	General information
GeORG[1]	Crate a data base with a geological model of the URG and its geothermal potential	It includes data of the geology, thickness, temperature, heat in place of the main reservoirs in the URG. Those area grouped in Malm, Main Oolite, Muschenkalk, Permo-triassic sandstones and Basement rocks. Information in other scales is available too.
Hessen 3D [2]	Provide information of the deep geothermal potential of Hesse	Its covers from the structural model to the geothermal potential including the uncertainty Analysis. It is divided in the units: "Pre-Permian" (subdivided into "Central German Threshold" and "Rhenoherzynic with Phyllite Zone") over Rotliegendes, Zechstein, Buntsandstein and Muschelkalk to the Tertiary and Quaternary as a combined unit.

[1] EU-Projekt GeORG | Project (geopotenziale.org)
[2] Geothermisches Potenzial: Projekt Hessen 3D | Hessisches Landesamt für Naturschutz, Umwelt und Geologie (hlnug.de)

Freymark et al., 2015 [3]	predict the present-day subsurface temperature of Hesse	3D model of Hessen that differentiates 7 sedimentary units. From structural to temperature mode. It considers gravity and thermal data.
Frey et al., 2021[4]	Integrated 3D geological modelling	3D model in the northern Upper Rhine Graben by joint inversion of gravimetry and magnetic data
Van der Vaart et al., 2021[5]	Quantifying model uncertainty of a geothermal 3D model	The model considers the group of the tertiary sandstones and calculate the uncertainties in a model based on the input data.

4.3 Belgium, region Flanders

The development of the geothermal exploration in Flanders Belgium started in 2015 with the drilling of the deep geothermal doublet in the Carboniferous Limestone Group. The following information correspond to the Geological (G3Dv3) and hydrogeological (H3D) 3D layer model of Flanders (Deckers J., 2019), available in Dutch.

1. Wells

The wells in Flanders are shown in Figure 5. The wells were used to build the geological model. The data is available in the general data base DOV[6].

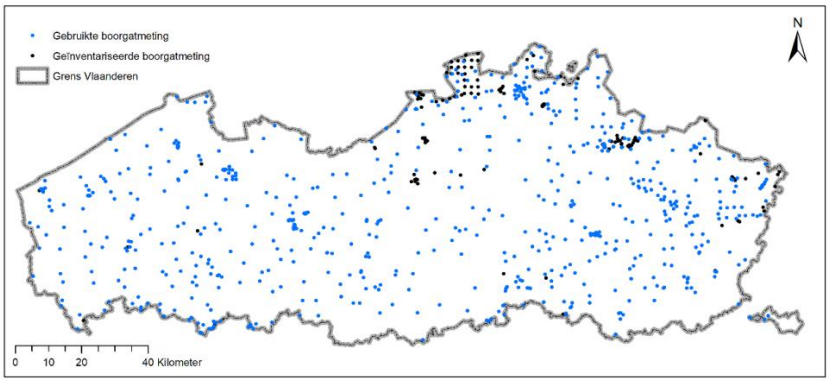


Figure 5 Summary of locations of wells with well logs that were inventoried for the layers of the model.

2. Seismic

The seismic information is located in the beforementioned database. The target horizons for deep geothermal projects in Flanders are located at the eastern side of the region, Hatched zone in Figure 6. It has been characterized with faults systems on the shallow and deep subsurface, in the Heers and

[3] https://doi.org/10.1016/j.egypro.2015.07.837
[4] https://doi.org/10.1016/j.tecto.2021.228927
[5] https://doi.org/10.1127/zdgg/2021/0286
[6] Drilling | Dov (vlaanderen.be)

Namurian formations respectively. Figure 7 shows the area in detail with the information related to the seismic campaigns.

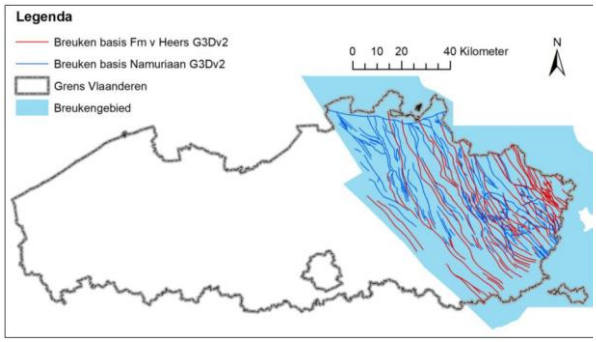


Figure 6 Overview of the location of what is referred to in this report as "the fracture area,", the fracture sets at the bases of the Heers Formation (shallow) and the Namurian (deep) from the G3Dv2 model are also shown, complete description in (Deckers J., 2019).

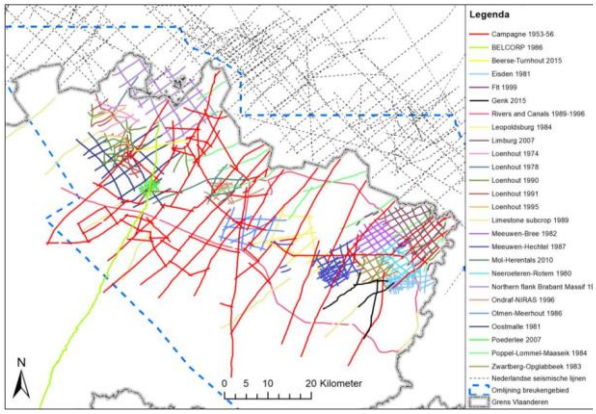


Figure 7 Overview of the different seismic campaigns used for the layout of the model in the fracture area. The fracture area is outlined in blue dashed lines. (Deckers J., 2019)

3. 3D-Models

The geothermal potential in Flanders has been defined between 300 and 3000 m. Figure 8 show the areas with potential in Belgium.

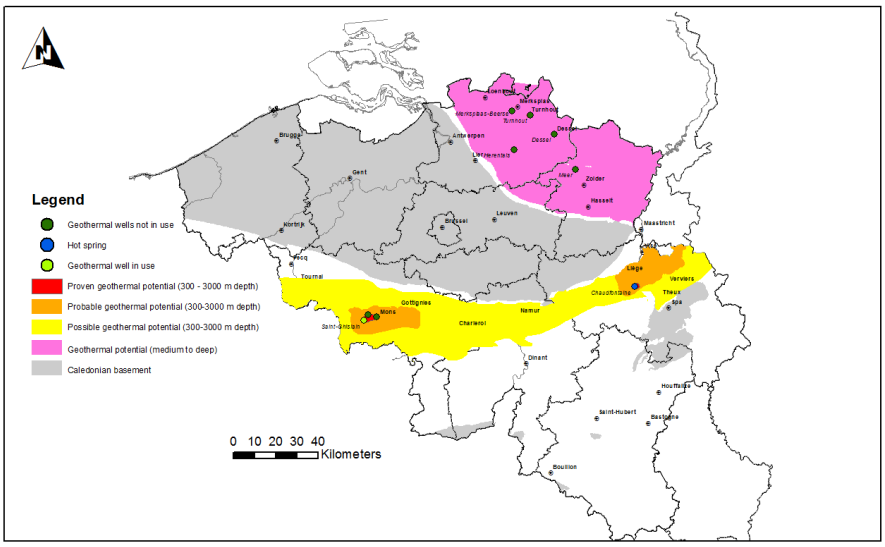


Figure 8 Medium to deep (300-3000m) geothermal potential map of Belgium. (Loveless, et al., 2015)

The area in pink is the Campine Basin, it has been studied due to the importance in the lower carboniferous carbonates. This area is showed in Figure 9, the geothermal projects are located in the Namurian group. The geothermal projects are mentioned with status in Section 4.7, except for

Loenhout, which is a gas storage project. Detail information the reader is referred to (Broothaers, et al., 2021). The current official geological model in Flanders is the G3Dv3.

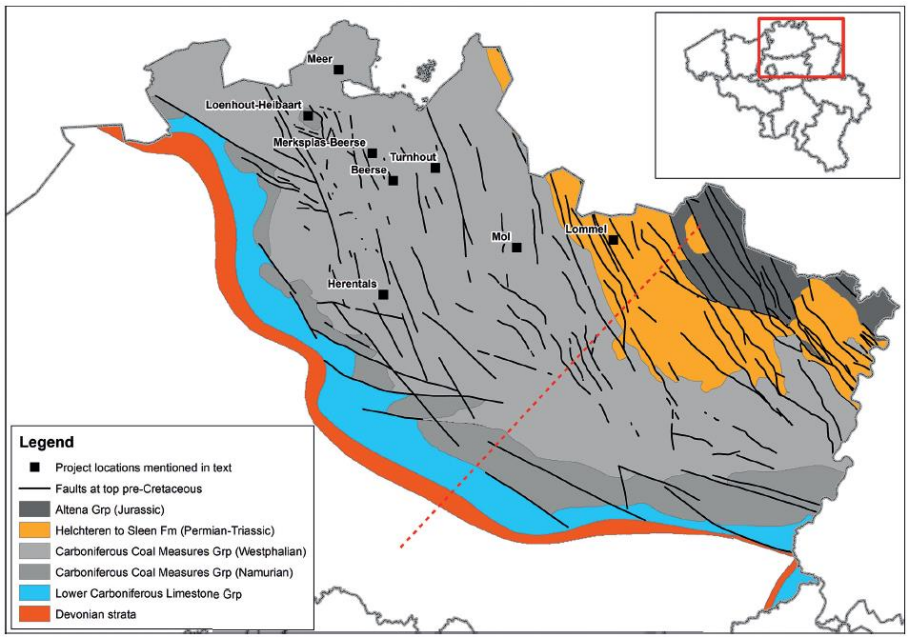


Figure 9: Pre-Cretaceous subcrop map of the Belgian Campine Basin based on the G3Dv3 model by Deckers et al. (2019).

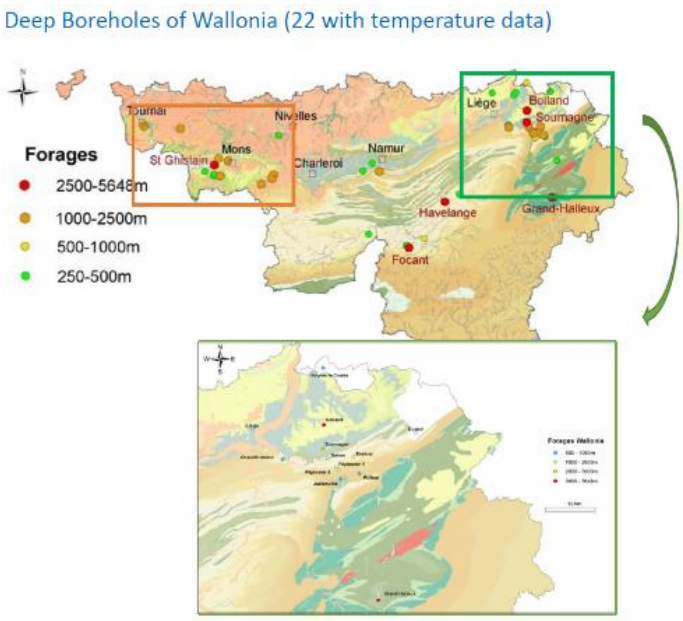
4.4 Belgium, region Wallonia

The use of the geothermal potential in Wallonia began in the 50's with the geothermal well "Turnhout". It was followed for 5 wells in the 70' 80's. Some of them currently working as geothermal projects, Saint-Ghislain, Douvrain and Ghlin, all in the region of Mons. The current situation in geological information were given by the geological Survey in 2020 (Petitclerc, 2020). The defined reservoirs in Wallonia are Sandstone and conglomerate from Permian and Upper Trias, limestones from Upper Torunasian to Visean (Dinantian), Devonian limestones from Eifelian, Giventian and Frasnian, and in the Lower Devonian sandstone and quartzite.

1. Wells

The most important wells are shown in Figure 10. Those wells have temperature data, which is useful for the determination of potential geothermal zones. The well data is available in the database Géoportail de la Wallonie[7].

[7] Données géologiques de base (GEOLOGIE) - Série | Géoportail de la Wallonie



	Drilling	Depth (m)	Geothermal Gradient (°C / km)
Hainaut Charleroi Tournai	Saint-Ghislain	5403.0	32.30
	Jeumont (France)	4338.0	20.44
	Epinois	2009.0	23.50
	Paturages	2000.0	29.70
	Fontaine l'Evêque	1900.0	23.69
	Ghlin	1579.0	38.60
	Douvrain	1447.3	42.70
	Vieux-Leuze	1536.0	24.66
	Rieu du cœur	1342.0	31.64
	Quévy	1275.0	29.58
	Tournai	1271.0	29.75
	Marcinelle	1254.0	19.92
Liège Herve	Bolland	3001.3	22.00
	Soumagne	2512	19.70
	Chaudfontaine	1229.0	31.33
	Ensival	1020.4	4.71
	Tilleur	942.0	29.51
	Fouron le Comte	866.0	31.82
Ardenne	Havelange	5648.0	20.30
	Grand-Halleux	3225.5	19.22
	Focant (S27)	3208.0	26.10
	Wépion	2310.0	22.17

Figure 10 Deepest geological information in Wallonia, (Petitclerc, 2020).

2. Seismic

The seismic information is shown in Figure 11. Four of these acquisitions were done before 1980. The new 2D seismic campaign is represented like DGE 2020, also mentioned the Action plan section.

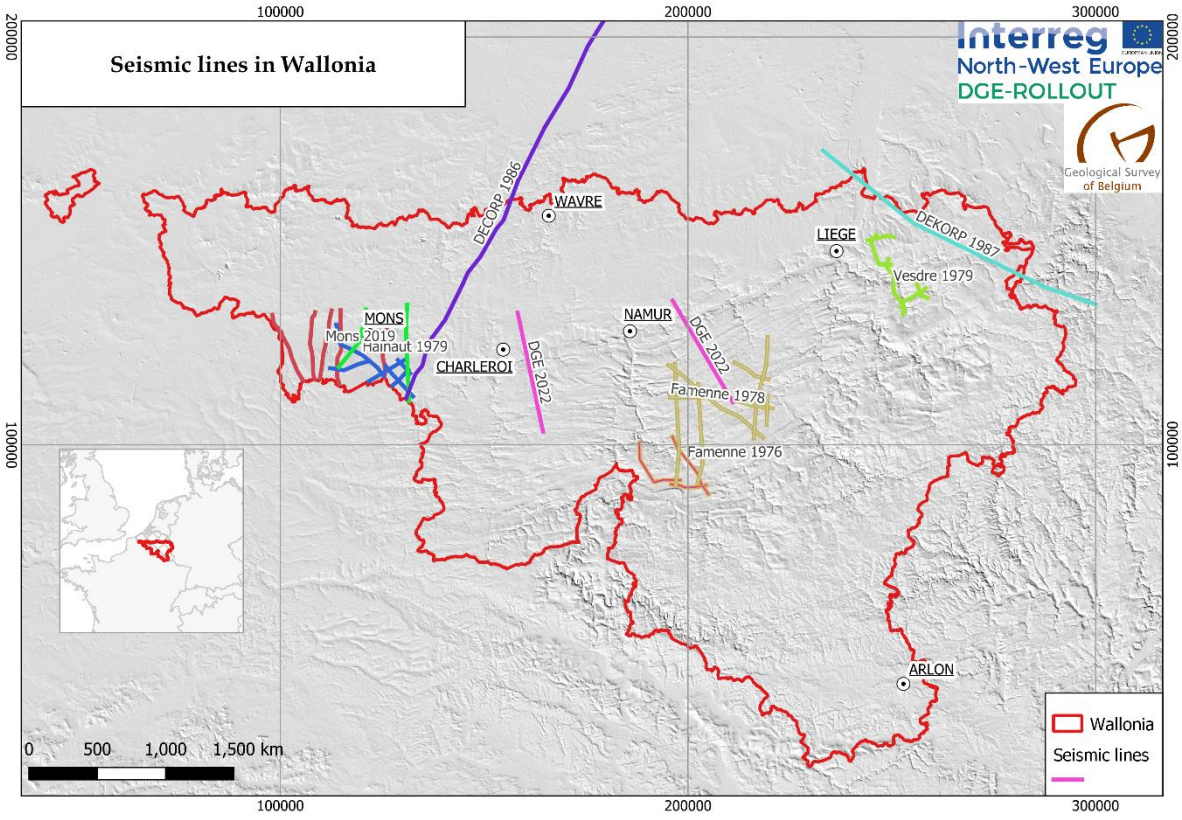
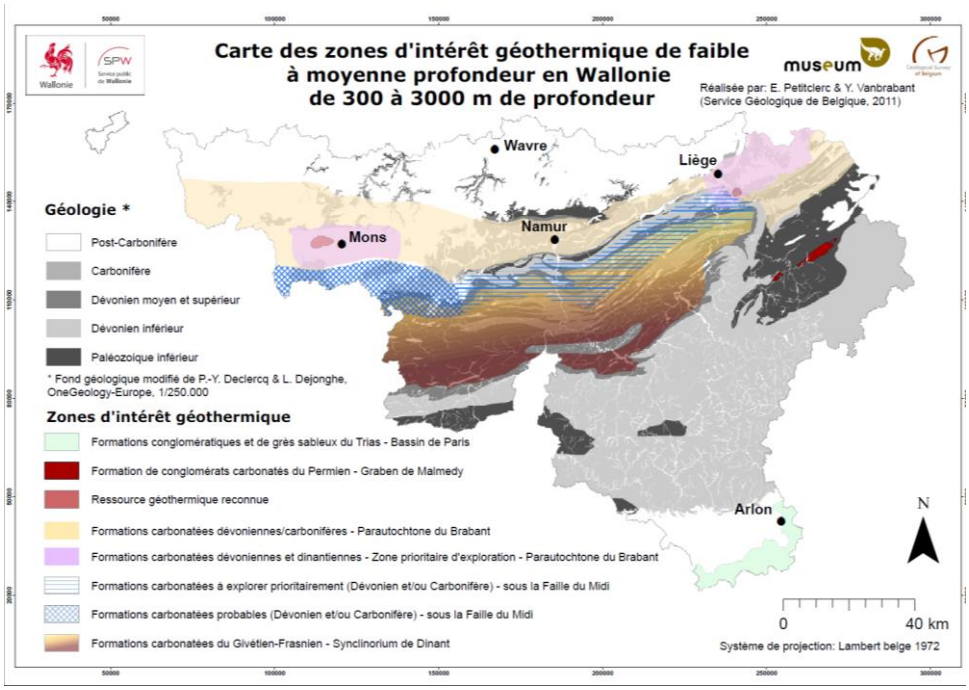


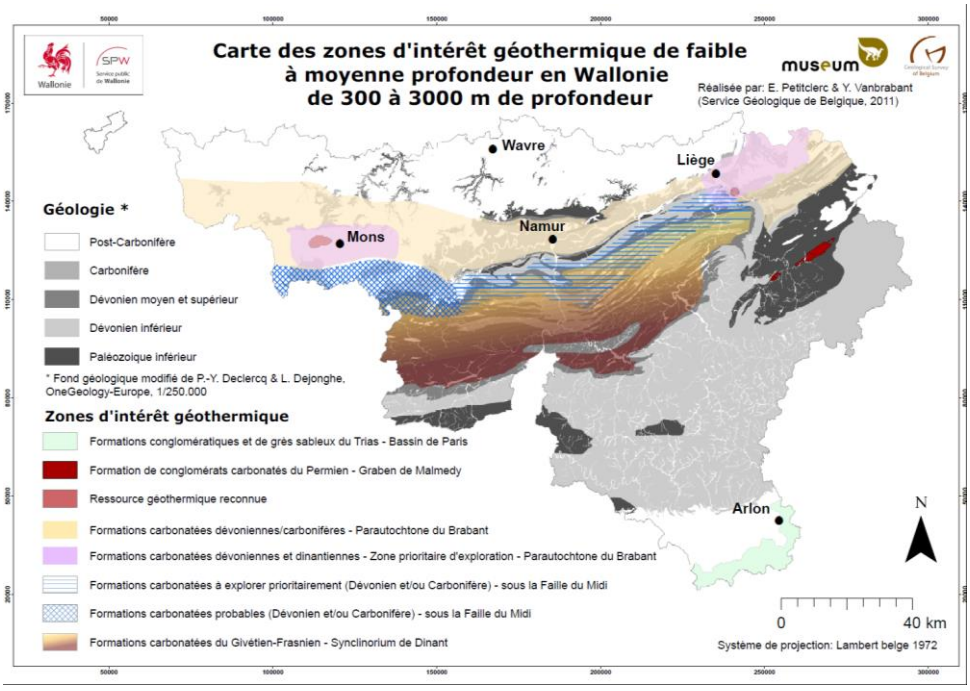
Figure 11 Seismic lines in Wallonia, after (Petitclerc, 2019) and (Petitclerc, 2020)

3. 3D-Models

The geothermal potential in Wallonia has been divided in shallow to medium (Map 7) and deep (Map 8). For the last one, the potential geology are rocks from the carboniferous and Devonian., their lithology are carbonates. The model of the Dinantian top and thickness in Liege Basin has been investigated in the DGE Roll-out project (Petitclerc, 2020).



Map 7 Shallow to medium depth geothermal areas of interest in Wallonia, (Petitclerc, 2020)



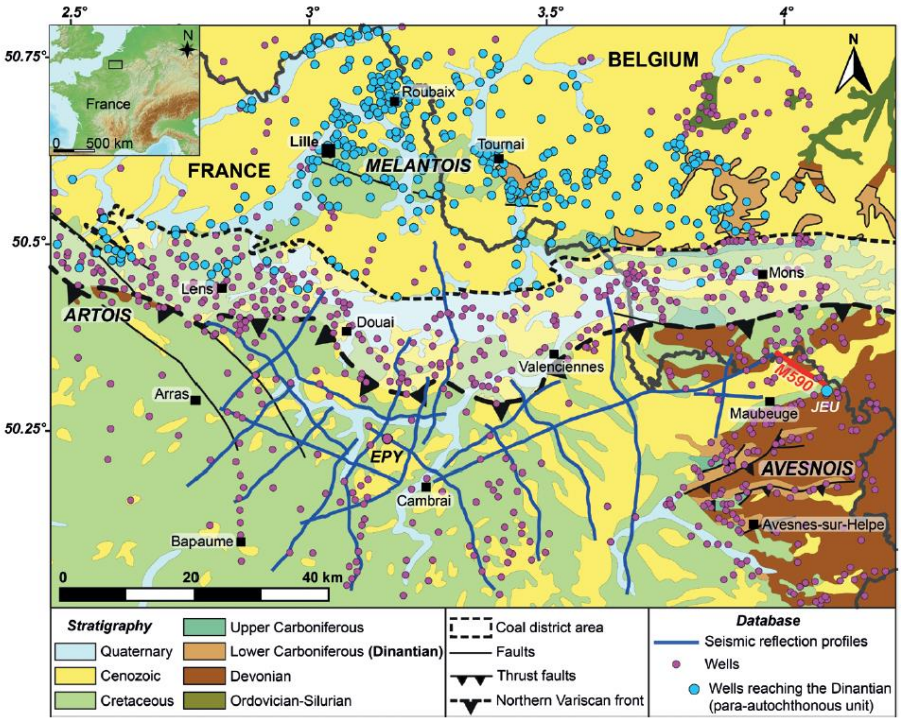
Map 8 Deep geothermal areas of interest in Wallonia, (Petitclerc, 2020).

4.5 France

In 2009, a study was carried to asset the French geothermal resources in the 6 different sedimentary regions in France: Paris Basin, Aquitaine Basin, Limagne Graben, the Rhine Graben, the Rhône Graben/ Provence Valley, and the Bresse Basin. (Jaudin, et al., 2009). In this report the data is referred to the modelling of the Dinantian carbonates in the Paris Basin, northern France.

1. Wells and Seismic

The well and seismic data is shown in Map 9. In total 1,128 wells are displayed as points, in blue color the ones are shown which have reached the Dinantian. The seismic data include 21 profiles, 532 km in total, which have been reprocessed. The range of investigation depth is from 0 to 7 or 8 km. (Laurent, et al., 2021)

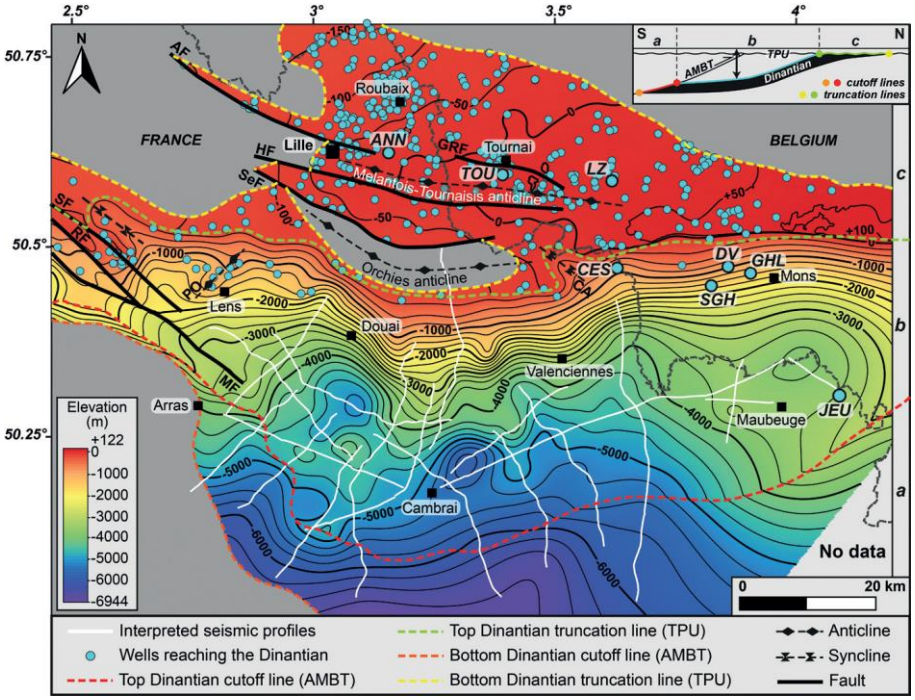


Map 9 Simplified geological map of the modelled area extracted from the geological map of France reporting the location of the boreholes and seismic reflection profiles used to produce the 3D model, complete description in (Laurent, et al., 2021).

2. 3D-Models

The area of the 3D model extends over 125 km E–W, and over 86 km N–S. It represents a surface area of 10,750 km2. The Dinantian reservoir is shallow in the Lille metropolitan area (< 200 m depth) and it

reaches 1,000–3,000 m depth beneath the coal basin district. The maximum depth is at the southern end of the study area (approximately 7,000 m).



Map 10 Depth structural map of the top of the Dinantian, extracted from the 3D model, (Laurent, et al., 2021).

4.6 Netherlands

The geothermal exploitation in the Netherlands started in 2007, and in 2021 the geothermal system including 1 shallow system were 26, the heat storage project of Mijnwater Energiecentrale Heerlen is excluded, and 19 of these systems were operational. The probed reservoirs are in Cenozoic, Upper Jurassic – Lower Cretaceous, Triassic, Rotliegend and lower Carboniferous (Dinantian) and Devonian horizons, (Ministry of Economic Affairs and Climate Policy, 2022).

The well and seismic data in Netherlands is open data after a confidentiality period of 5 years. This data can be accessed via the NLOG[8] data center. ThermoGIS[9], a dedicated geothermal energy information system, was developed by TNO. Computed heat in place maps, geothermal potential, achievable flow rates, etc., of the different plays and reservoirs can be viewed as well as the locations of well and seismic data.

[8] www.nlog.nl
[9] Map Viewer | Thermogis

1. Wells

The information about wells are categorized by development, appraisal, explorations and others, Figure 12. The visualization is using ThermoGIS. Detailed information can be downloaded in the TNO data center.

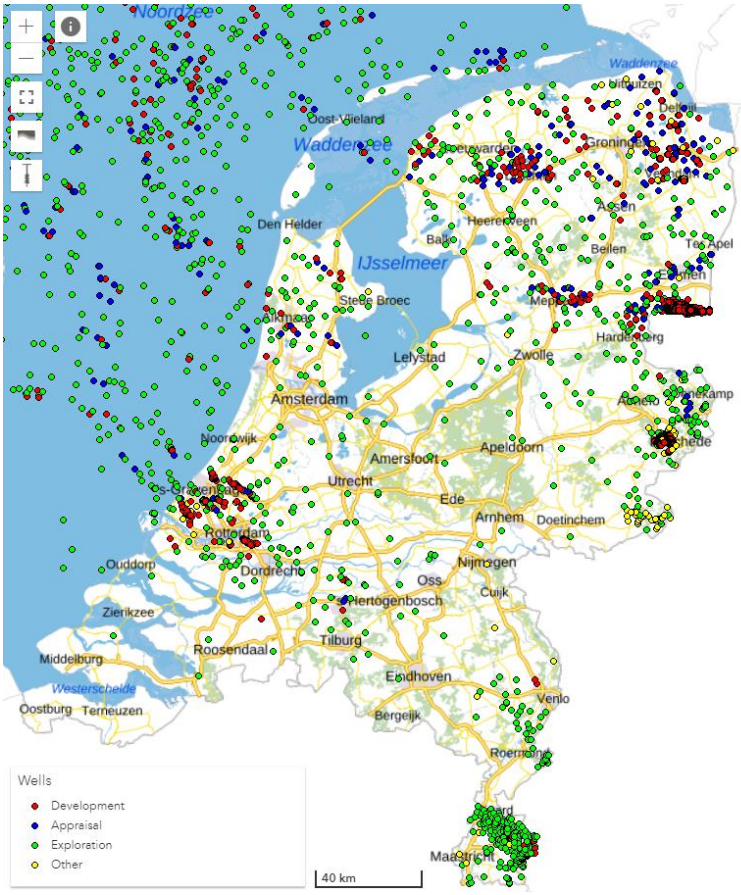


Figure 12 Wells in the Netherlands, extract focus in on-shore area, open data information in ThermoGIS.

2. Seismic

Figure 13 shows the seismic data in the Netherlands - 2D digital seismic and 3D seismic surveys. The 2D analog data has been omitted for visualization reasons.

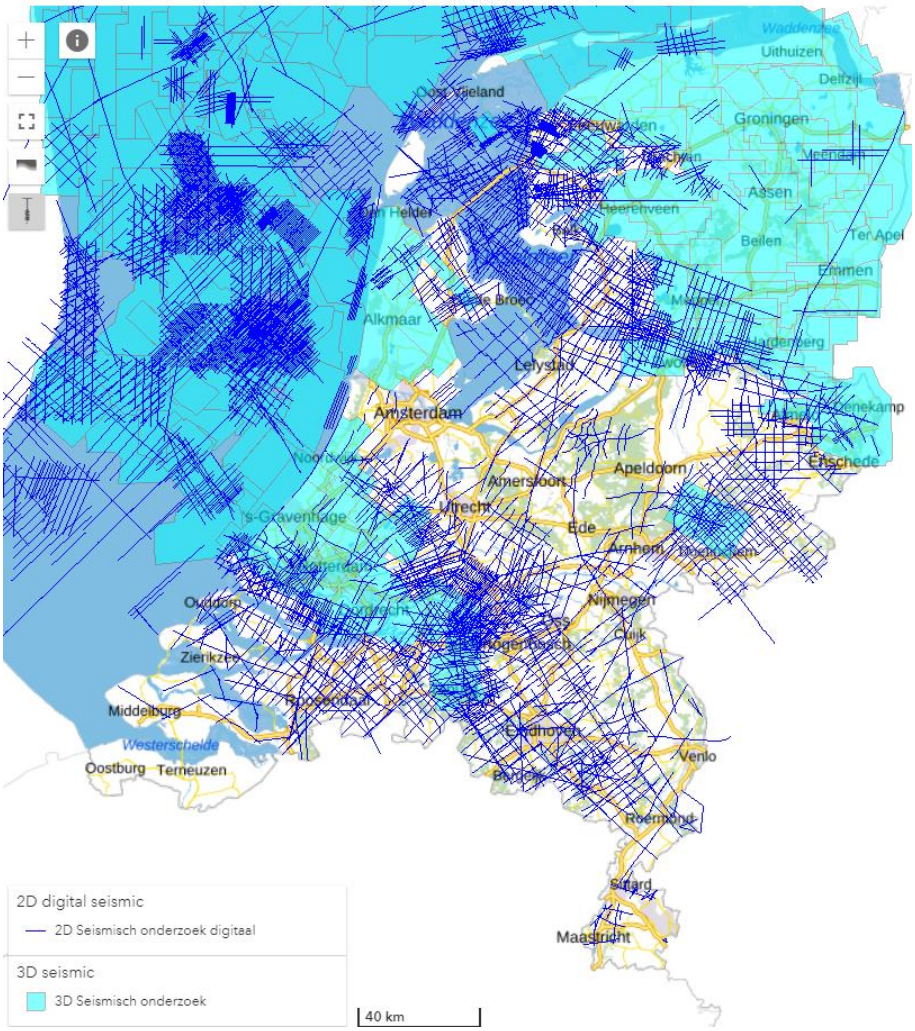


Figure 13 Seismic data in the Netherlands, 2D digital seismic and 3D seismic surveys.

3. 3D-Models

The geothermal play and reservoirs have been described for the Netherlands (Mijnlieff, 2020). Figure 14 shows the distribution of the aquifers with geothermal potential related with the geological age. Figure 15 shows the total heat in place in the Netherlands. The geothermal potential per aquifer and formation can be consulted in ThermoGIS.

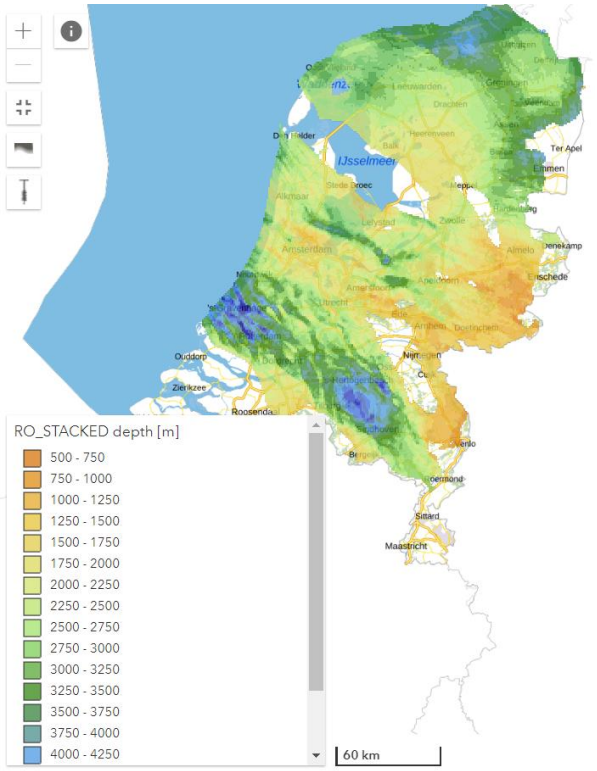


Figure 14 Top of aquifer related to the Permian reservoir, information available in ThermoGIS.

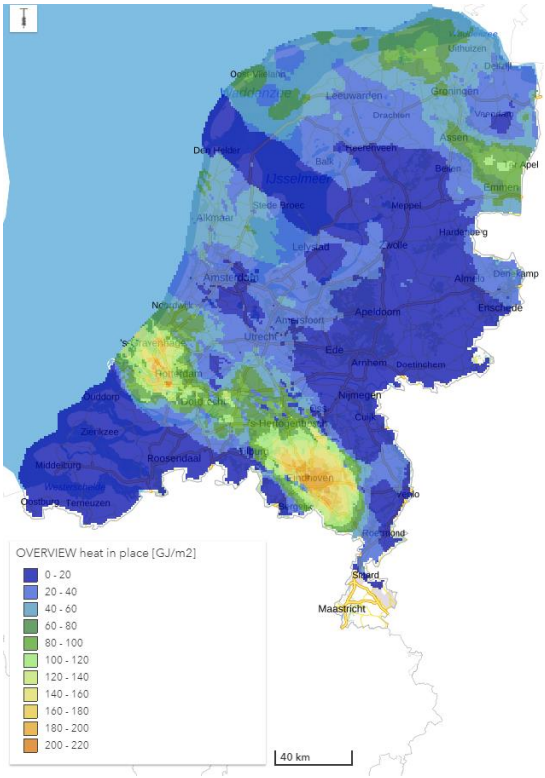


Figure 15 Heat in place in the Netherlands, information available in ThermoGIS.

4.7 All regions - Geothermal projects

The geothermal projects begin years before drilling the first well. The exploration starts in a regional level and becomes local and with more detail. The project stage definition is based on the Deep Geothermal Guideline (Höllen, 2010). The description of each stage is:

Base estimates Project idea is due to evidence of a higher geothermal gradient than the average and the probability of the existence of a hydrothermal reservoir. The area of investigation is regional. In the geotechnical pyramid is the Geosystem.

Preliminary planning focus on the understanding of the geothermal play. The regional geological model is built with new seismic or reprocessed seismic. The area of investigation is still on a regional scale. In the geotechnical pyramid is the "Play".

Draft planning It is the definition of "Prospects". The presence of hydrothermal reservoir based on indirect data, in general, geophysical prospection. The units with geothermal potential are analysed, as well as the geological controls and possible reservoir conditions. The scale of the prospects becomes local.

Exploration In this stage the first well is drilled. With the verification of the geological model and conditions the play is renamed “Reservoir”, its resolution is local. It is a decision point based on the results of the reservoir evaluation test.

Operation It is the development of the geothermal plant with well(s) in production and surrounding surface infrastructure.

The existing deep geothermal projects of the regions which are part of the DGE-Rollout project are named in Table 8. The number is related to the project stage. Some projects have been abandoned or cancelled for diverse reasons, the majority is in the exploration stage (4), the decision point after the first well. The nomenclature next to the projects stage refers to why the project has been abandoned (a) or temporary closed (tc): (d) dry well, (g) geological features, (s) seismicity, (r) reservoir conditions, public acceptance (p), (tp) technical problems, and (f) financial aspects.

Table 8 Geothermal projects in the regions part of DGE-Rollout project and stage, further description in text.

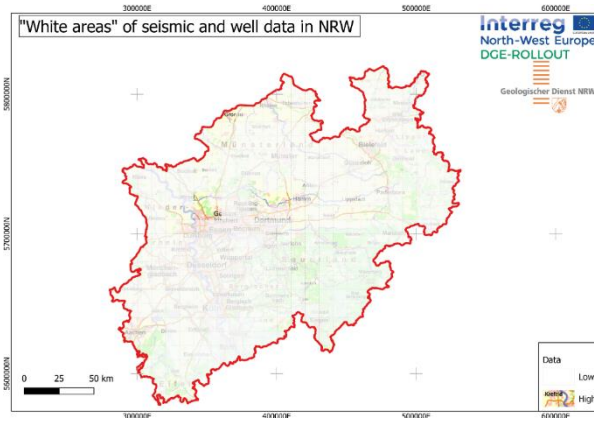
Region	Target Horizon			
	Cretaceous / Jurassic	Triassic / Permian	Lower Carboniferous	Devonian Massenkalk
G-NRW			Weisweiler 3	Kabel Zero (Hagen) 3
G-URG	Bühl 4 (a:g)	Insheim 5 Bruchsal 5 Trebur 4 (a:d) Bellheim 4 (a:g) Offenbach 4 (a:d) Brühl 4 (a:s,p)	Landau 5 Rhein-Pfalz (Speyer) 3	
France		Rittershoffen (URG) 5 Hurtigheim (URG) 2 Eckbolsheim (URG) 2	Soultz-sous-Forêts (URG) 5 Vendenheim (URG) 5 (a:s) Illkirch (URG) 4	

			Cronenbourg (URG)	4 (a:r,f)	Wissembourg (URG)	4	
			Les Sources (Woerth)	3	Develpment in Hauts de France	3	
B-Flanders			Lommel	2	Balmatt (Mol)	5	
					Beerse	4	
					Turnhout	3	
					Herentals	3	
					Merksplas	4 (a:r)	
					Meer	4 (a:g)	
B-Wallonia					Saint-Ghislain (Mons)	5	Mapping 1
					Douvrain (Mons)	5	
					Ghlin (Mons)	5	
					Porte de Nimy	2(a)	
Netherlands	9 Projects	5	Triassic:		Californië IV	4 (a:s,f)	Mapping 1
	Honselersdijk	5 (tc: tp)	Vierpolders	5			
			Oostvoorne	5			
	Berkel en Rodenrijs	5 (tc: tp)	Permian:		Californië V	4 (a:s,f)	
			8 Projects	5			
	The Hague Geothermal Energy Leyweg	4 (tc: f)	Luttelgeest II	4			

5 Identification of areas with lack of data

The description of the existing data and model let us to have an overview of which areas need more information to reduce uncertainties. Map 11 is the result for NRW. The white area indicates where is less information in the state. Figure 16 is the “White spots” layer over the heat in place layer in the

Netherlands. In this case, the white colours are given by a class scale. It depends on the type of seismic. In this point of view, areas with 3D seismic surveys have better values than areas with 2D analog seismic data. More details can be found in ThermoGIS.



Map 11 White areas in North Rhine-Westphalia. The white color is stronger in areas where seismic or well data don't exist.

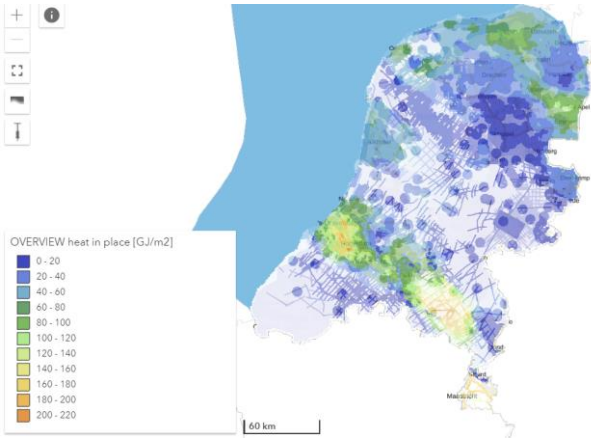


Figure 16 "White spots" layer over the heat in place layer in the Netherlands. The white colors are given by a weighted scale, depending on the seismic type and well data.

The white areas information map is not available for all the regions. In the case of the URG the uncertainties calculation in the geological models defines areas where additional exploration data is required (van der Vaart, et al., 2021).

6 Prioritization criteria for further subsurface mapping campaigns

The essential information depends on the project's stage, it can refer to the start or continuation of the development of the geothermal project. Table 9 is the summarize of the projects stage defined in section 4.7. Each project stage is described with the key point, which is the decisive information to go to the next stage. The data column means the expected information but not always available. The subsurface mapping campaigns are the recommended according to the literature (Siler, et al., 2019). The outcome are the results of those campaigns. The last column gives the scale resolution of analysis and the geotechnical names according to Moeck (Moeck, et al., 2020)

Table 9 Stages definition with data and activities related to each phase.

	Project's stage	Key point	Data	Subsurface mapping campaigns	Outcome	Geotechnical name and resolution
1	Base estimates	Probability existence of hydrothermal reservoir	2D geological data (Maps, sections) Hydro-chemical properties	2D regional seismic	Reprocessing seismic Regional geological model	Geosystem Regional

			Well data (regional)			
2	Preliminary planning	Definition of geothermal play	Lithology Fault system	Geophysical exploration (seismic 2D, 3D, gravity, magnetics)	3D geological model	Geosystem/Play Regional/Local
3	Draft planning / Prospection	Geological model and settings in a local area	Geomechanics model (stress field) Heat flow model	Drilling-induced fractures of analogue wells	Geothermal potential Uncertainties model	Play/Prospect Local
4	Exploration	Reservoir characteristics (rock and fluid)	Well logs Petrophysical data Flow rates	Well drilling Well logging Hydraulic test	Verification of geological model Conditions in the reservoir	Reservoir Local
5	Operation	Geothermal plant with well(s) in production	Reservoir behavior	Seismic monitoring	Detail geological model	Reservoir Local

7 Action plan

The action plan contains tasks/steps that are planned to be carried out to reach the goal to characterize more horizons with their potential. For this purpose, the individual action steps are listed and their respective target horizons and depth are described in Table 10. Furthermore, the action plan names organisation who will be in charge of carrying out each task. Timeframes are referred to for knowing when these tasks will be completed. All of this, leads to a description of the desired outcome.

Table 10 Action plan

Action Step	Target Horizon	Depth [m]	Responsible Organisation	Timeframe [YEAR]	Data outcome	Legal Base	Outcome
DGE-Rollout Network	Dinantian carbonates	0 - 4000	Geologischer Dienst Nordrhein-Westfalen - Landesbetrieb (GD NRW)	2022 - 2027	Networking		Annual meeting of network
2D-Seismik im Münsterland	Cenoman-Turon limestone Dinantian carbonates Devonian Massenkalk	0 - 6000	Geologischer Dienst Nordrhein-Westfalen - Landesbetrieb (GD NRW)	2021 - 2022	New 2D-Seismic	Parliament resolution of March 20, 2019: Use heat potential - facilitate the use of geothermal energy	The aim of the investigations is to use seismic measurements to scout the subsurface for future geothermal opportunities.
2D Seismik Rheinland-	Cenoman-Turon limestone Dinantian carbonates Devonian Massenkalk	0 - 3500	Geologischer Dienst Nordrhein-Westfalen - Landesbetrieb (GD NRW)	2022-2023	New 2D-Seismic	Parliament resolution of March 20, 2019: Use heat potential - facilitate the use of geothermal energy	The aim of the investigations is to use seismic measurements to scout the subsurface for future geothermal opportunities.

Geothermale Charakterisierung des Münsterlandes	Dinantian carbonates Devonian Massenkalk Devonian Massenkalk	0 - 6000	Geologischer Dienst Nordrhein-Westfalen - Landesbetrieb (GD NRW)	2021 - 2022	Laboratory measurements, 3D modelling, New 2D-Seismic	Parliament resolution of March 20, 2019: Use heat potential - facilitate the use of geothermal energy	Through an online platform municipality can locate particularly suitable locations of optimal geothermal potential to build up a geothermal plant to decarbonize heat supply.
Netherlands Seismic Campaign for Geothermal Energy' (Seismische Campagne Aardwarmte Nederland) or 'SCAN' programme for short	Rotliegend sandstone Dinantian carbonates Devonian Massenkalk	0 - 6000	EBN (Energie Beheer Nederland) and the Netherlands Organisation for applied scientific research (TNO) for the Ministry of Economic Affairs and Climate policy (EZK)	2018 - 2025	New 2D-Seismics, Re-Processing of 2D-Seismics Planning, design & drilling of data acquisition wells		The purpose of the SCAN program is to complete the map of the Dutch deep subsurface by researching the areas that were historically left 'blank' because of their lack of oil and or gas potential. By openly sharing this data SCAN will help support future determination of geothermal potential in these areas.

MEET (H 2020) Belgium	Lower Devonian sandstones and quartzites in Havelange, Belgium.		The MEET Project (Multidisciplinary and multi-context demonstration of Enhanced Geothermal Systems exploration and Exploitation Techniques and potentials)		Reprocessing Seismic Data		Boosting the development of Enhanced Geothermal Systems (across Europe in various geological contexts
CONDROZ 2022 Belgium	Dinantian carbonates		GBS	2022 - 2023	New 2D-Seismics		In particular the seismic campaign, intended to be undertaken by GSB, aims to link major parts of the transnational area DGE-ROLLOUT is focusing on. The better understanding of the Midi-Eifelian-Aachen thrust, and hence the establishing of a link between the regional geological settings of northern France, Belgium (Wallonie) and western Germany is crucial for the geological interpretation of the transnational area, and will significantly enhance the understanding of the geothermal potential of the entire project area.
France	Dinantian limestones in Hauts de France		BRGM	2020-2022	Reprocess the vintage seismic data		Borehole data analysis: petro physical characteristics of the Dinantian limestones.

8 Evaluation of Progress

All the geothermal target horizons (Table 2) have been analysed in the stage 1 “Base estimate” at least in one region of the DGE Roll out project countries (Table 8). The next stage in the geothermal projects is 2 “Preliminary planning”, still in regional scale. In theory, when a play has been defined in the target horizons, the following projects start from stage 3 “Draft planning”. In fact, it starts again in stage 2 “Preliminary planning” because the exploration, geological model and geothermal potential are now in a local scale. This particularity is displayed in Figure 17, the common risk and inversion graphic of a geothermal project. At the bottom, the image has the stages of a geothermal project in colour according with the given definition. Another difference with the predefined project’s stage is stage 4 “Exploration”, it is divided into exploration and development. Because the success of the first well doesn’t imply the development or exploitation of the reservoir. This happened in the project Brühl (URG), where the seismicity and low public acceptances have discontinued the project.

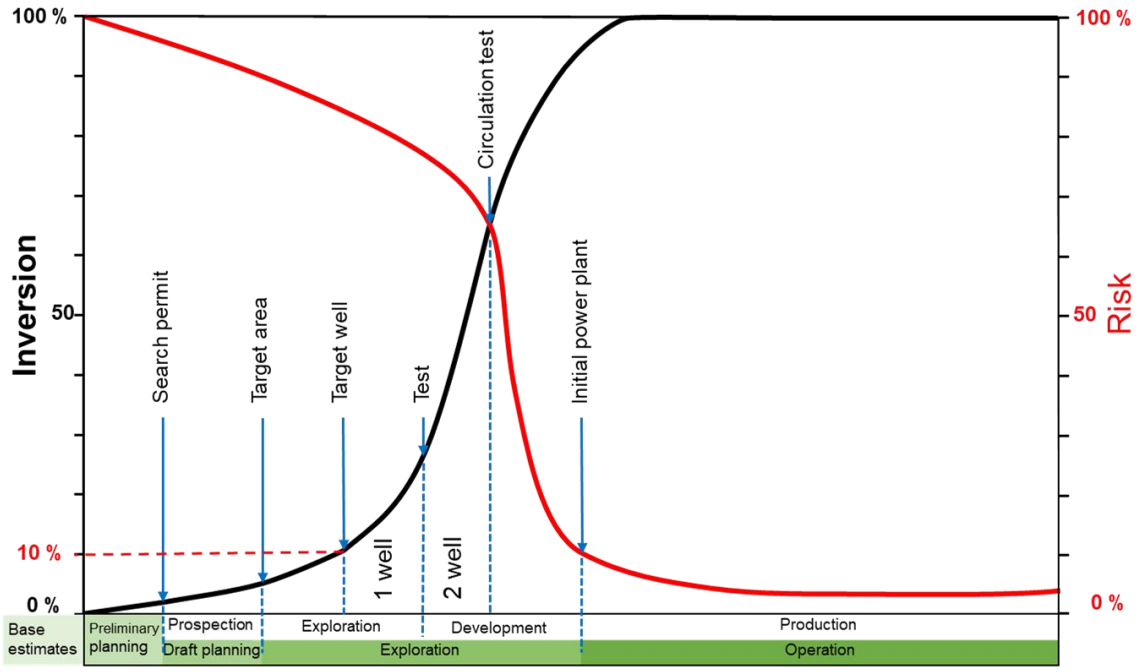


Figure 17 Development of a geothermal project, after (Deckert, 2022).

Therefore, activities that reduce uncertainty for the characterization of potential geothermal energy horizons and the impact they have are proposed as a way of "progress evaluation". For example, activities that have conventionally been carried out during advanced phases of the project such a exploratory well drillings or seismic monitoring. This is done in 3 and 5 stage respectively, but some projects such as Weisweiler implement it from the exploration stage the natural seismic characterization of the area and differentiate between induced and natural seismicity.

Another example is the exploratory wells carried out by the government. In the SCAN project, it is expected that this type of wells will allow a greater investment of private projects, in addition to the fact that the information is public in the Netherlands.

In Table 11 Evaluation of progress in the geothermal horizons.Table 11 are the potential and proved geothermal horizons grouped by geological period, the current subsurface mappings campaigns mentioned in the action plan, and the impact of this activity. This impact is a qualitative measure based on the existence of this type of information. For example, a 2D seismic line in an area where with old exploration seismic campaigns is medium impact, but in an area where no data is existing is high impact.

Table 11 Evaluation of progress in the geothermal horizons.

Geologic Era	System/ Period	Activity - Country	Scale Regional / Local	Impact
Cenozoic	Paleogene	SCAN: 2D seismic – N SCAN: Well drilling – N	Regional Local	High High
Mesozoic	Cretaceous	2D seismic Münsterland – G 2D seismic Rheinland - G	Regional Regional	High High
	Jurassic			
	Triassic	SCAN: 2D seismic – N SCAN: Well drilling – N	Regional Local	High High
Paleozoic	Permian	SCAN: 2D seismic – N SCAN: Well drilling – N	Regional Local	High High
	Carboniferous	SCAN: 2D seismic – N SCAN: Well drilling – N 2D seismic Münsterland – G 2D seismic Rheinland – G CONDROZ 2022 – B- 2D seismic	Regional Local Regional Regional Regional	High High High High High
	Devonian	2D seismic Münsterland – G 2D seismic Rheinland - G MEET: seismic reprocessing - B	Regional Regional Regional	High High Medium

8.1 The URG example

The present is an example of a play in development, with the potential reservoirs tested and characterized, focus on the geothermal projects, the timeline and results.

The URG has been developed as a geothermal play for more than 20 years. In this time several geothermal projects have been developed. An overview of those and their status are showed in Figure 18. With the projects classified in abandoned, implementation, discontinued, in operation, oil found, and balneology, the last two out of scope in this project.

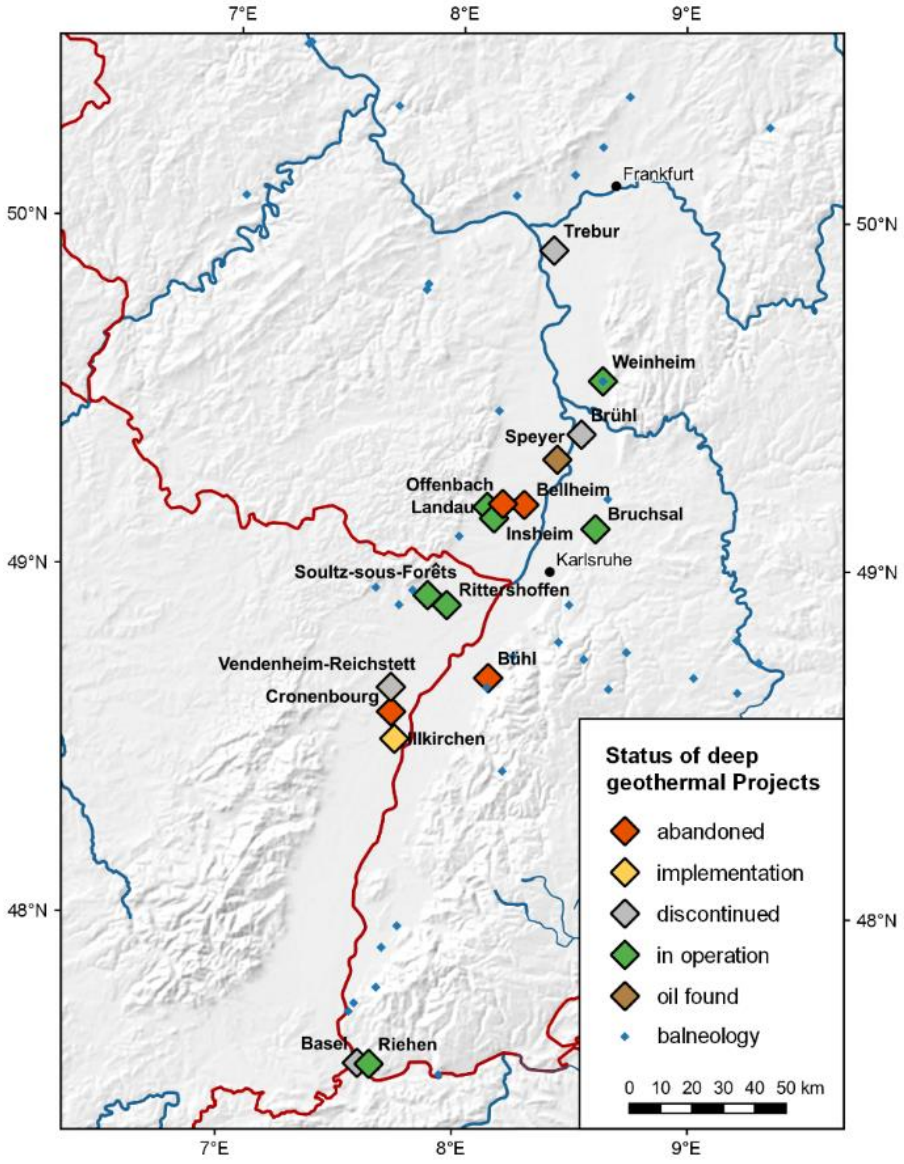


Figure 18 : Overview of the geothermal projects in the URG and their current status (Frey, et al., 2022).

The information available during the exploration phase of the geothermal potential in the Upper Rhine Graben was related to hydrocarbon exploration, seismic and borehole data during the 70´s. Later during the 80´s data related to the first geothermal wells was acquired and the Soultz-sous-Forets project has provided information about the reservoirs. The development of projects after year 2000 are related to Renewable Energy Sources Act, which came into force in that year, (Frey, et al., 2022).

Table 12 shows a summary of the deep geothermal projects in the URG, the timeline of the project with the available phase's dates, and the target horizons. The first row of table 12 shows the study of the European Cenozoic Rift System as a base estimate for geothermal energy. Then the second row shows the Upper Rhine Graben like a play. The following rows are the geothermal projects, where the

scale change from Play (regional) to Prospect (local). All the abandoned and discontinued projects are shown in grey, and which phase each of them reached.

In the phase Preliminary planning to draft planning is not possible to give a date because is more a transition when the geothermal potential has been calculated and the first well is planning. So far, a relation between new studies and new projects success can yet not be related. Nonetheless, the availability geology and reservoir information of the oil and gas industry let the development of the geothermal play.

Table 12 Example of Project's stage and its resolution in the upper Rhine graben area.

Project stage	Base estimates	Preliminary planning	Draft planning	Exploration		Operation	Keuper	Muschelkalk	Bundsandstein	Permian	Carboniferous / Basement
				Exploration	Develoment						
Scale / Project	Geosystem	Play / Prospect	Prospect	Reservoir		Reservoir					
European Cenozoic Rift System	1970										
Upper Rhine Graben		1970									
Bühl				1979							
Cronenbourg		1973		1980							
Bruchsal		1979		1983	2001	2005					
Soultz-sous-Forêts		1984		1987	1997	2014					
Riehen		1980		1988	1989	1994					
Offenbach				2004							
Bellheim				2005							
Landau		2003		2005	2006	2007					
Insheim		2007		2008	2009	2012					
Brühl		2005		2012							
Rittershoffen		2011		2012	2015	2017					
Trebur				2016							
Vendenheim				2017	2019	2020					
Illkirch				2018							
Hurtigheim											
Rhein-Pfalz											
Hardt		2022									

9 Literaturverzeichnis

Broothaers, Matsen, et al. 2021. Deep geothermal energy in the Lower Carboniferous carbonates of the Campine Basin, northern Belgium: An overview from the 1950's to 2020. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften.* 2021, Bd. 172, 12, S. 211-225.

Deckers J., De Koninck R., Bos S., Broothaers M., Dirix K., Hambsch L., Lagrou, D., Lanckacker T.,Matthijs, J., Rombaut B., Van Baelen K. & Van Haren T. 2019. *Geologisch (G3Dv3) en hydrogeologisch (H3D) .* Mol Belgium : VITO, 2019.

Deckert, Hagen. 2022. Geothermische Energiegewinnung im Raum Speyer und Schifferstadt. 2022.

Derer, Christian E., Schumacher, Markus E. und Schäfer, Andreas. 2005. The northern Upper Rhine Graben: Basin geometry and early syn-rift tectono-sedimentary evolution. *International Journal of Earth Sciences.* 2005, 94, S. 640–656.

Frey, Matthis und van der Vaart, Jeroen. 2022. *Socio-economic potential mapping for Deep Geothermal Energy, Deliverable T1.2.3.* Germany : DGE-Rollout Project, 2022.

Frey, Matthis, et al. 2022. Assessment of Deep Geothermal Research and Development in the Upper Rhine Graben. *Geothermal Energy.* 2022, 10.

Frey, Matthis, et al. 2021. Integrated 3D geological modelling of the northern Upper Rhine Graben by joint inversion of gravimetry and magnetic data. *Tectonophysics.* 2021, 830.

Glaas, Carole, Vidal, Jeanne und Genter, Albert. 2021. Structural characterization of naturally fractured geothermal reservoirs in the central Upper Rhine Graben. *Journal of Structural Geology.* 2021, 148.

Höllen, Arne. 2010. Tiefe Geothermie. Berlin, Deutschland : VBI-Leitfaden, 2010.

Jaudin, F., et al. 2009. French geothermal resources survey. *French geological Survey BRGM.* 2009.

Laurent, Aurore, et al. 2021. Modelling the 3D geometry of the Dinantian carbonate geothermal reservoir in northern France. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften.* 2021, Bd. 172, 12, S. 293-305.

Loveless, Sian, et al. 2015. Country update for Belgium. Melbourne, Australia : s.n., 2015.

Lutz, Manfred und Cleintuar, Max. 1999. Geological results of a hydrocarbon exploration campaign in the sothern Upper Rhine Graben (Alsace Centrale, France). *Bulletin für angewandte Geologie.* 1999, Bd. 4, S. 3-80.

Mijnlieff, Harmen F. 2020. Introduction to the geothermal play and reservoir geology of the Netherlands. *Netherlandns Journal of Geosciences.* 2020, 99.

Ministry of Economic Affairs and Climate Policy. 2022. Natural resources and geothermal energy in the Netherlands. *Annual review 2021.* 2022.

Moeck, Inga, et al. 2020. Geothermal Play Typing – Current Development and Future Trends of a Modern Concept for Geothermal Resources Assesstment. 2020.

Petitclerc, Estelle. 2020. How deep is geothermal energy in Wallonia? *Geoconnect³d Webinar.* [Online] June 2020.

—. 2019. WP T2 Decision and exploration support Walloon. 2019, Bd. Minutes.

Reinecker, John, et al. 2019. EXPERIENCES AND CHALLENGES IN GEOTHERMAL EXPLORATION IN THE UPPER RHINE GRABEN. *European Geothermal Congress 2019.* 2019.

Rotstein, Yair und Schaming, Marc. 2008. Tectonic implications of faulting styles along a rift margin: The boundary between the Rhine Graben and the Vosges Mountains. *TECTONICS.* 2008, 27.

Schill, E, et al. 2017. Hydraulic performance history at the Soultz EGS reservoirs from stimulation. *Geothermics.* 2017, 70, S. 110-124.

Siler, Drew L., et al. 2019. Three-dimensional geologic mapping to assess geothermal potential: examples from Nevada and Oregon. *Geothermal Energy.* 2019, Bd. 7.

van der Vaart, Jeroen, et al. 2021. Quantifying model uncertainty of a geothermal 3D model of the Cenozoic deposits in the northern Upper Rhine Graben, Germany. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften.* 2021.

Van Wees, Jan-Diederik, et al. Geothermal Energy in the Netherlands: The ThermoGIS project.

Vidal, Jeanne und Genter, Albert. 2018. Overview of naturally permeable fractured reservoirs in the central and southern Upper Rhine Graben: Insights from geothermal wells. *Geothermics.* 2018.

PROJECT PARTNERS

Geologischer Dienst NRW

Fraunhofer IEG

vito

Geoscience for a sustainable Earth
brgm

ebn

DMT

Geological Survey of Belgium

TECHNISCHE UNIVERSITÄT DARMSTADT

TNO innovation for life

RWE

PROJECT SUP-PARTNERS

RUHR UNIVERSITÄT BOCHUM
RUB

GeoThermal ENGINEERING

MORE INFORMATION

Dr Martin Salamon (Project Manager)
Martin.Salamon@gd.nrw.de
+49 2151 897 230
www.nweurope.eu/DGE-Rollout
@DGE–ROLLOUT

SUPPORTED BY

europiZe UG
Dr Daniel Zerweck
+49 176 6251 5841
www.europize.eu

europiZe
realising projects