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A Methodology for Resource assessment and application to core countries

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1 Introduction and scope

This document gives a definition for resource assessment for the IEE funded project GEO-ELEC. This projects aims at developing a pan-European map based overview of the location of geothermal resources which can be developed in the 2020 and 2050 timeline horizons for electricity production.

The resource potential reflects the prognosed electricity which can be produced on an economic basis. The economics depend on three factors

1. Natural quality of the resource (Temperature, depth, geochemistry, natural production flow rates)
2. Engineered quality of the resource (enhanced production flow rate)
3. Conversion process and costs of producing the resource, including costs for reinjection of fluids if necessary

The quality of the resource is primarily determined by subsurface temperature and production flow rates, as these determine the power which can be produced from the subsurface:

Depth of the resource is an important economic factor as in most geothermal production systems drilling to 1-5km depth is the most important cost factor.

Prognosed Levelized Costs Of Energy (LCOE) [EUR/MWhe] is considered as evaluation criterion for the potential. Current LCOE show a considerable range depending on the resource quality. In Magmatic areas where production systems are marked by high temperatures (>200C) close to the surface (<1km), marked by high natural flow rates, the LCOE can be as low as few 10s of EUR/MWhe. For production systems with moderate temperature (ca 200C) at large depth and requiring enhanced flow rates through Engineered Geothermal Systems, LCOE is about 200-300 EUR/MWhe. This illustrates the importance of the natural resource quality and its strong variability in the subsurface.

Tester et al., 2006; IEA,2011, JPGE,2012 point out that the developments in geothermal energy depend strongly on technological advancements capable of removing barriers to produce fluids from deeper in the earth at moderate increase in costs. This includes various prognosed technical advancements:

1. (exploration) Reduction of uncertainty on the resource quality prior to costly drilling
2. (drilling) reduction of drilling costs (e.g. spallation drilling)
3. (stimulation) enhancing natural flow rates
4. (supercritical) calbility to detect and preduce from supercritical fluids.
5. (conversion) improvement of overall conversion efficiency and reduction of the cooling temperature.

The effects of anticipated enhancements are to be included in the resource assessment to assess the resource base with timelines of 2020 and 2050.

The pan-European map view will be based on a unified reporting protocol and resource classification for geothermal resource assessment. The resource reporting protocol and underlying data is described in this document.

The resource assessment protocol is based on resource assessment concepts developed in the oil and gas industry, which have been adopted in a adjusted form for geothermal resource assessment and reporting. This protocol has been based on the following work:

- Beardsmore et al., 2010. A protocol for estimating and mapping the global EGS potential.
- AGEA, 2010. Australian code for reporting of exploration results, geothermal resources and geothermal reserves: the geothermal reporting code
- CanGEA, 2010. The Canadian geothermal code for public reporting

These documents describe a protocol to classify and estimate geothermal reserves and resources. Further, we used input from resource classification approaches developed in the oil and gas industry (Etherington et al., 2007).

In our approach we start in chapter 2 with an introduction of basic terminology. As a next step in chapter 3 we define the guidelines for estimating theoretical and technical potential for enhanced low permeability high enthalpy systems in detail for different stages in the workflow (play, lead, prospect, contingent resources, reserves) for different play types.

Geothermal power plants in Bouillante (Guadeloupe-France)

2 Basic definitions and best practices

2.1 Basic definitions

mcKelvey (Fig. 1) and **project approach:** Key to resource assessment and classification is the concept of the McKelvey diagram (Figure 1), and a project oriented approach in which resources develop progressively from being inferred at an early exploration stage towards becoming discovered after drilling and finally economically recoverable at the production stage. In the exploration the transition from an inferred (undiscovered) to a discovered resource is determined by drilling the reservoir, which is capable to prove the occurrence of the resource and to appraise the productivity.

Play, leads and prospects (Fig. 2): In the geothermal exploration workflow prior to drilling, the identification of a prospective reservoir location starts off with a so-called play concept. A geothermal **play** is a geographically (and in depth) *delimited area* where *specific subsurface conditions* allow to obtain sufficiently high flow rate of sufficiently high temperature, with suitable pressure and chemical conditions. A **lead** is a *particular subsurface reservoir* which has been identified by surface exploration studies (e.g. MT). A **prospect** is a location which has been studied thoroughly by surface exploration and has been earmarked to be drilled.

Conversion efficiency and power (Fig. 3)

$$Efficiency(\eta) = \frac{Tx - Ts}{Tx + Ts + 2*273.15K}\eta_c \qquad \text{(eq.1)}$$

Tx = production temperature [C]
Ts = average surface temperature [C]
η_c= relative efficiency compared to carnot efficiency [-]

$$Power\ (E) = \ Q\ \rho_{fluid}\ c_{fluid}(Tx - Tr)10^{-6} \quad \text{(in MW)} \quad \text{(eq.2)}$$

Q = flow rate [m3/s]
Tr = re-injection temperature [C]
ρ_{fluid}= fluid density [kg/m3]
c_{fluid}= fluid specific heat [J/kg/K]

Eq. 1 is based on Tester et al. (2006) and Di Pippo (2008). Their analysis shows that for a large variety of conversion designs covering a spectrum from using produced steam directly to drive turbines (flash) as well as binary systems, that η_c= 0.6 (Fig. 2).

For binary systems Tr is about 80C above average surface temperature (Beardsmore et al., 2010).

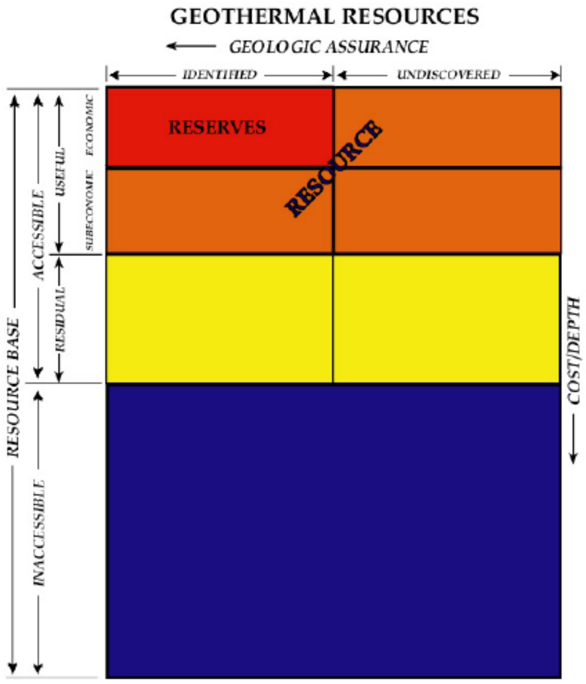

Figure 1: McKelvey diagram representing geothermal resource and reserve terminology in the context of geologic assurance and economic viability (from Williams et al., 2008))

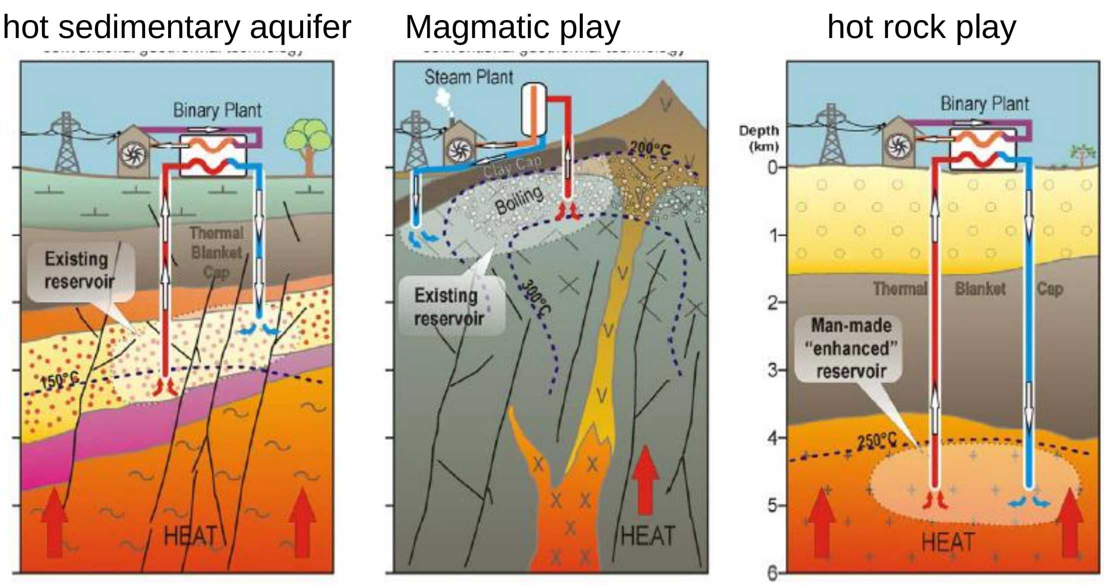

Figure 2: example of different play types for geothermal systems (modified from Hot Rock ltd). Hot sedimentary aquifers and magmatic plays can be mostly developed without enhancing the reservoir, relying on natural aquifer and fracture permeability. Magmatic plays can generally produce very high temperatures at shallow depth. Low permeable rock plays are located in regions of elevated temperatures (caused by radiogenic heat production, elevated tectonic heat flow, or vertical heat advection trough deep fault zones).

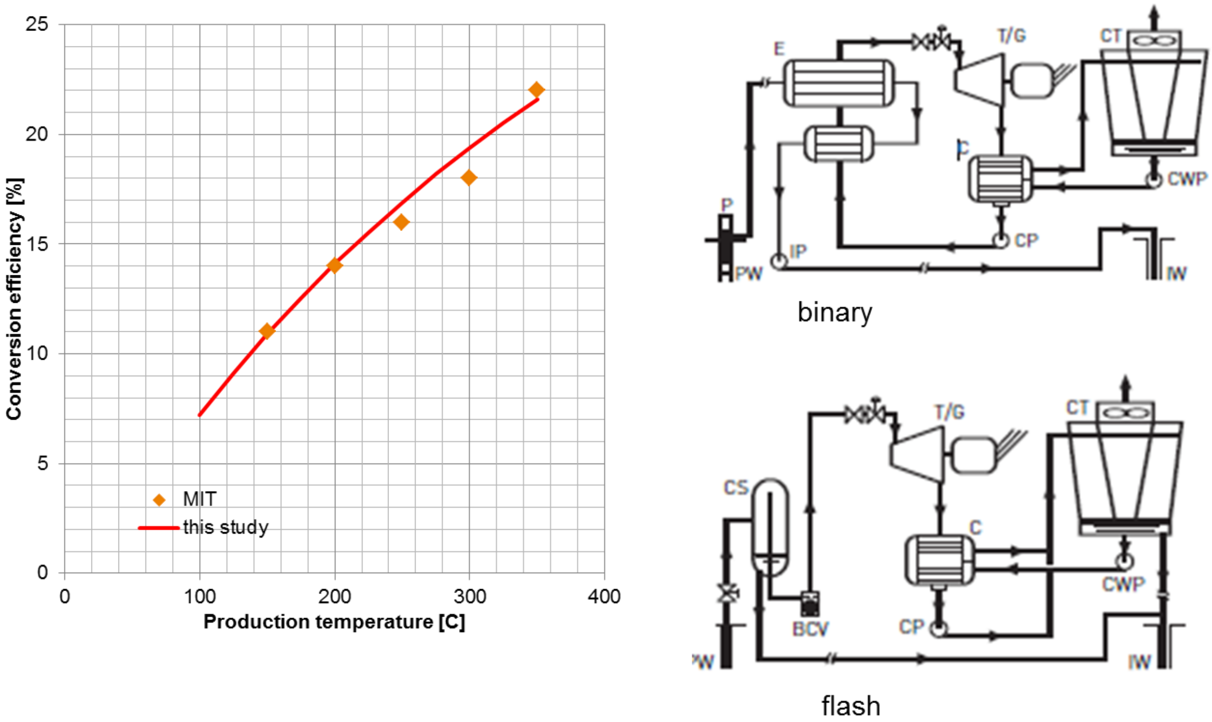

Figure 3: Practically achieved conversion efficiencies of various geothermal production installations (left), including both binary and flash systems (right) (after Tester et al., 2006). The best fit curve fitting eq.1 for Ts =10C is achieved with η_c =0.6.

2.2 The hydrocarbon best practice

Resource classification in the hydrocarbon industry is very well matured and serves as an excellent starting point for geothermal classification and reporting. The publication of Etherington and Ritter (2007) forms the latest extension of the Petroleum resource management system accepted by oil and gas industry. Here we summarize the main aspects of the classification scheme which can be useful for geothermal energy. It should be emphasized that geothermal resources in geothermal systems differ from both minerals and petroleum resources by being renewable through recharge, albeit usually at a slower rate than energy is extracted. The rate of this recharge can vary significantly from system to system, and can be stimulated to a varying degree by production.

Prospective Resources are those quantities estimated to be commercially recoverable from yet undiscovered accumulations assuming a discovery is confirmed. While there is always a gray area, a discovery is declared when results of one or more exploratory wells support existence of a significant quantity of potentially moveable hydrocarbons. For geothermal this would agree with confirming a resource through drilling. Discovered quantities should be initially classified as *Contingent Resources*. A portion of these quantities that can be recovered by a *defined commercial project* may then be reclassified as *Reserves*. Commerciality requires that the project form part of an economic venture and the organization claiming commerciality has a firm intention to develop and produce these quantities. Firm intention implies that there is high confidence that any current constraining contingencies will be overcome and that development will be initiated within a reasonable time frame. A reasonable time frame for the initiation of development depends on the specific circumstances and varies according to the scope of the project. In oil and gas industry five years is recommended as a benchmark, however in geothermal development and especially EGS a longer time frame may be applied

Project Status and Commercial Risk

In order to establish a resources reporting system, the classification takes into account the Project Maturity combined with commerciality (Figure. 5). Projects are characterized by quantitative estimates of their chance of reaching producing status. These estimates have several sources of uncertainty: Project Maturity reflects the actions (business decisions) required to move it towards commercial production.

The range of uncertainty of the recoverable, or technical potential of geothermal energy may be represented by either discrete deterministic scenarios or by a probability distribution. When the range of uncertainty is represented by a probability distribution, a low, best, and high estimate can be provided such that:

- There should be at least a 90% probability (P90) that the quantities actually recovered will equal or exceed the low estimate.
- There should be at least a 50% probability (P50) that the quantities actually recovered will equal or exceed the best estimate.
- There should be at least a 10% probability (P10) that the quantities actually recovered will equal or exceed the high estimate.

For *Reserves*, the incremental terminology (Proved, Probable, Possible) is used and is denoted for cumulative portfolio quantities as: 1P for Proved, 2P for Proved plus Probable and 3P for Proved plus Probable plus Possible.

For *Contingent Resources*, terminology is recommended to align with that used in Reserves. While no formal terminology describes the incremental categories, the cumulative scenario notation is 1C/2C/3C. It is emphasized that the Contingent Resource categories utilize the same criteria as for Reserves but the development projects do not meet commercial specifications.

No incremental category labels are defined for *Prospective Resources* and cumulative scenarios remain described by the terms low, best and high estimate.

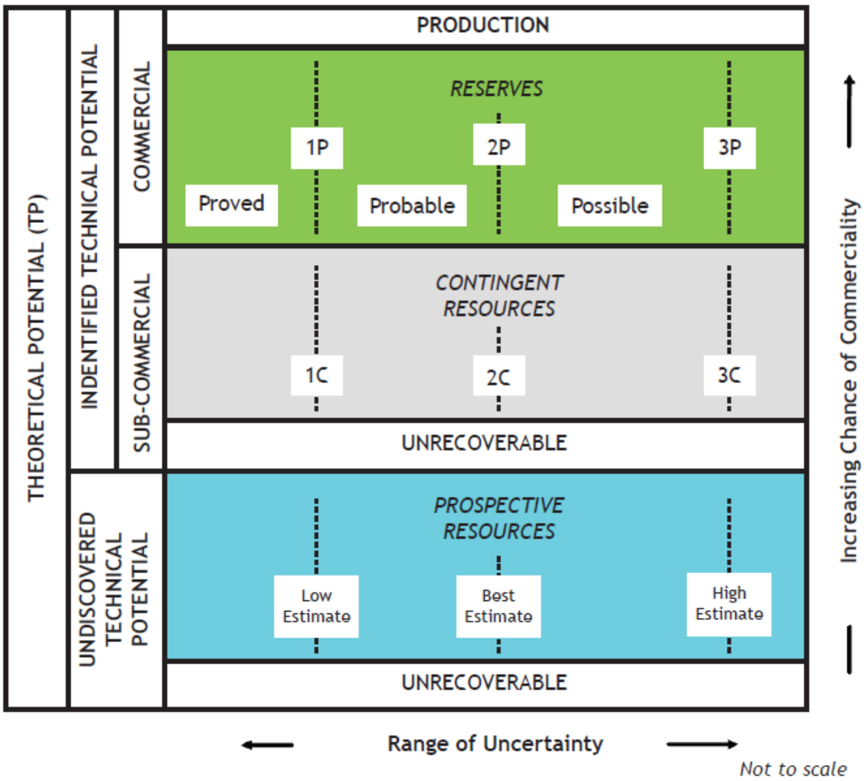

Figure 4: uncertainty ranges for resource and reserves estimates, and commerciality axis of projects moving them up from prospective resources to contingent resources to reserves (from Etherington and Ritter, 2007).

2.3 Existing reporting code: the Australian Code

The Australian Geothermal ReportingCode (AGEA-AGEC, 2010) describes a general code for resource assessment at a stage that a resource is at least inferred at a *particular location*, and is not suited for a global assessment such proposed in Beardsmore et al. (2010) and as performed for IPPC (2011). The code is aimed at *transparency for investors*, and is generic worldwide for two geothermal plays (cf. Figure 5):

- D1: naturally convective systems (magmatic systems) and hot sedimentary aquifers
- D2: hot rock, suitable for stimulation

Reporting is subdivided in stages along the workflow process, being:

- A: pre drilling exploration technical data
- B: tenement, environmental and infrastructural data
- C : subsurface and well discharge data (exploration and production)

For any country in Europe this code is fully appropriate for reporting specific exploration outcomes and results on (contigent) resources and reserves, if publically available.

- For GEO-ELEC this code can be well used (especially Table 1 therein, here figure 6), however GEO-ELEC targets resources prior to selecting specific project locations, so we refrain from adopting these as is for our purpose

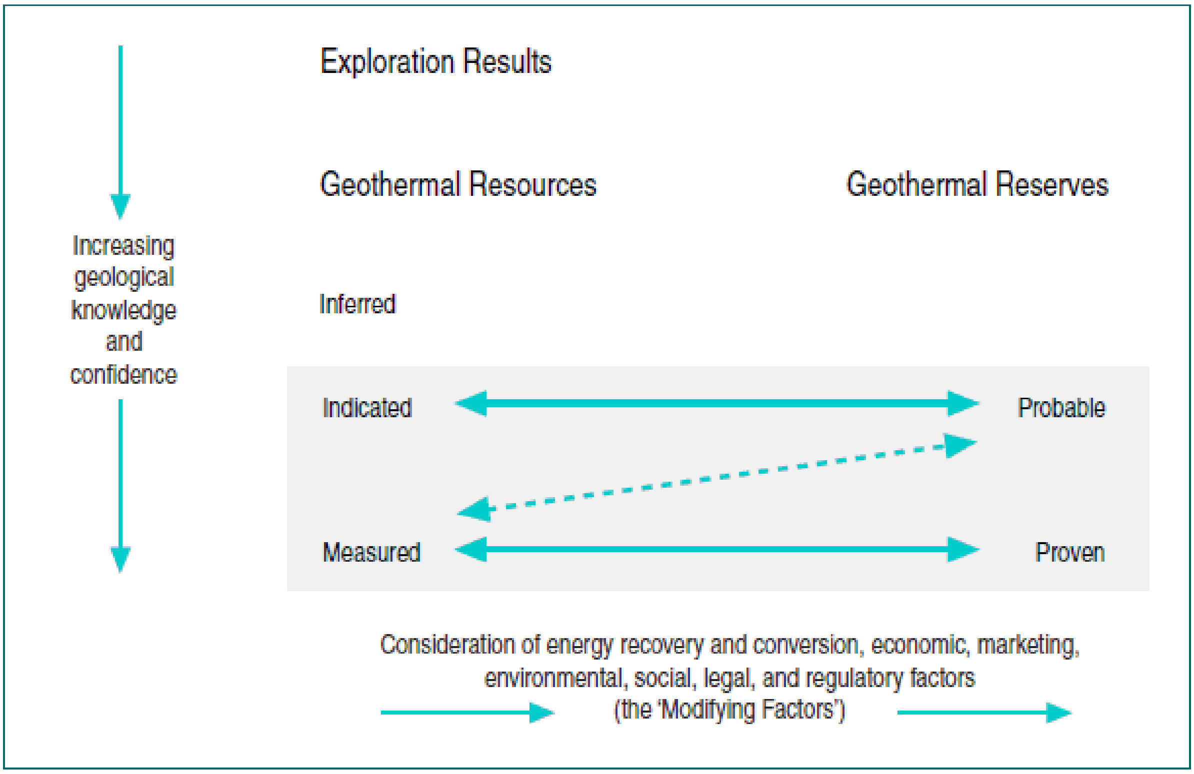

Figure 5. Categories of geothermal resources and reserves after the Australian Geothermal Reporting Code (from AGEA-AGEC, 2010).

Table 1 Summary of Resource and Reserve Classification

This Table should be used as a guideline only for those preparing reports on Exploration Results, Geothermal Resources and Geothermal Reserves. For full formal definitions of Geothermal Resources and Reserves, please refer to the Code text.

	Exploration Results	Resource			Reserve	
		Inferred	Indicated	Measured	Probable	Proven
Commerciality	No implications regarding commerciality.	Commerciality not yet established. Possibly feasible with current or future technology, prevailing and/or more favourable market conditions.			Commercial. Feasible with existing technology and prevailing market conditions.	
Definition	Data from exploration that is of material value to Geothermal Resource estimation, but which in itself is insufficient to define a Geothermal Resource category.	An area/volume that has enough direct indicators of Geothermal Resource character or dimensions to provide a sound basis for assuming that a body of thermal energy exists, estimating temperature and having some indication of extent.	A more reliably characterised volume of rock than the Inferred Geothermal Resource. Sufficient indicators to characterise temperature and chemistry, although with few direct measures indicating extent.	A drilled and tested volume of rock within which well deliverability has been demonstrated, with sufficient indicators to characterise temperature and chemistry and with sufficient direct measurements to confirm the continuity of the reservoir.	Equivalent to an Indicated Resource for which commercial production for the assumed lifetime of the project can be forecast; or Equivalent to a Measured Resource for which commercial production for the assumed lifetime of the project cannot be forecast with sufficient confidence to be considered a Proven Reserve. The chance of occurrence is 'more likely than not'.	Applies directly to production satisfying all Modifying Factors. Directly related to a Measured Resource for which commercial production for the stated lifetime of the project can be forecast with a high degree of confidence.
Correlation With Probabilistic Estimates					~P50	~P90
Units	As appropriate.	Thermal Energy in Place (PJ) with assumptions stated.	Thermal Energy in Place (PJ) and optionally Recoverable Thermal Energy (PJ), with assumptions stated. May also be reported as assumed electricity generation with assumptions and rate stated (MWe) or GWh in total.	Thermal Energy in Place (PJ) and optionally Recoverable Thermal Energy (PJ), with assumptions stated. May also be reported as assumed electricity generation with assumptions and rate stated (MWe) or GWh in total.	Thermal Energy in Place (PJ) and Recoverable Thermal Energy (PJ), defined in relation to a stated technology and recovery rate. Electricity generation should be presented as net electrical output (MWe) for a defined period or GWh in total.	Thermal Energy in Place (PJ) and Recoverable Thermal Energy (PJ) defined in relation to a stated technology and recovery rate. Electricity generation should be presented as net electrical output (MWe) for a defined period or GWh in total.

Figure 6: classification of resources and reserves (from AGEA-AGEG, 2010). Please not that Resource combines prospective (inferred and indicated) and contigent resources (measured) from Figure 4.

3 Proposed resource assessment in GEO-ELEC

Resource assessment in reporting can be subdivided in three levels (Figure 7):

- Level 1: Global European prospective resource assessment for producing electricity
- Level 2: Prospective undiscovered resource assessment for different play types
- Level 3: Contingent (discovered) resources and reserves

1. Global European prospective resource assessment for producing electricity	European wide assessment (cf. Beardsmore et al., 2010). Determine technical potential for different depth ranges for EGS, key input are base maps of temperature, and rock type to identify theoretical potential. Filter maps with information on natural reserve areas etc. Assume relatively low ultimate recovery in agreement with whole depth column (cf. IPCC, 2011). distinguish relative attractiveness, low, mid, high estimates according to drilling depth required to reach temperature
2. Prospective undiscovered resource assessment for different play types	Identify delimited areas with a particular play type (e.g. Hot Sedimentary Aquifer (HSA), magmatic and low permeability). Include data relevant to exploration of particular play types and exploration outcomes (cf. AGEA-AGEC, 2010) for exploration data relevant to resources assessment
3. Contingent (discovered) resources and reserves	From industry and government reporting obtain information on drilled prospects and producing reserves, play types, development type[1]

Figure 7: representation of the various levels of resource categorization progressing from global (level 1), to prospect based (level 2), to drilled and producing (level 3).

In depth the resource assessment is limited to 5 or 6.5 km for present developments, but may increase in the future. We therefore propose to develop two timelines, one based on 7 km for 2020 and one based on 10 km for 2050.

In GEO-ELEC we perform a global Level 1 assessment. In the GeoELEC project we assessed if sufficient information was available for level 2 and level 3 and easy to incorporate. The information gathering for the assessment was accomplished through data workshops and a data request sheet (see appendix A for details on a data acquisition sheet sent out for that purpose). It was concluded that insufficient data was available for a level 2 or 3 assessment. The details of the level 1 assessment is given in the following section

[1] There will be likeky problems for gathering confidential information from the private geothermal industry and for publically disclosing it. A minimum period of non public disclosure will apply to the most recent or on-going geothermal projects. For each of these projects authorization from several private organisations (owner, contractor, sub-contractor) will have to be requested. A regulatoryframework on that matter will have to be developed by IGA, similar to what may already be in force in mining and hydrocarbon explorations.

The assessment and map information will be presented in a public web-based information system (cf www.thermogis.nl/worldaquifer) containing key maps and data, such as spatially resolved temperatures.

3.1 Calculation of European Level 1 resource assessment

The level 1 assessment is based on the methodology of beardsmore et al., 2010.

Calculations are performed on a 3D voxel grid with a typical horizontal resolution of 10 km and a vertical resolution of 250m. The areas covered by this voxet covers the EU-27 countries including various other countries in western Europe. The area is delineated in Figure 8. In this approach, the potential maps are constructed from a vertical stack of sub volumes (voxel) with increasing temperature with depth. For each sub volume theoretical to practical potential is calculated, schematically illustrated in Figure 9. For each of the sub volumes the quantities in table 1 are determined, and vertically stacked to produce maps. The definition of these maps is given below.

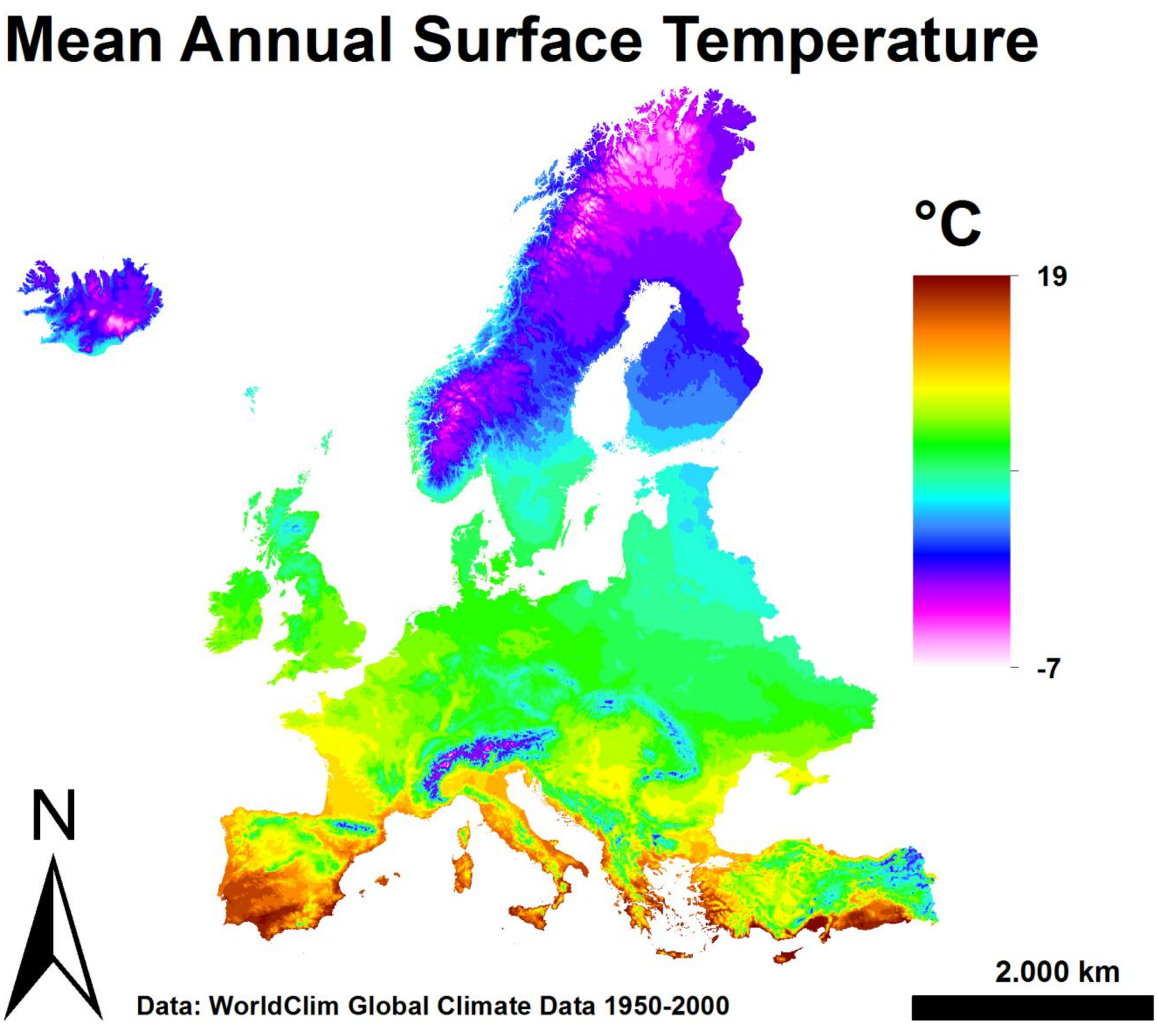

Figure 8: Countries covered by the potential assessment and mean average surface temperature.

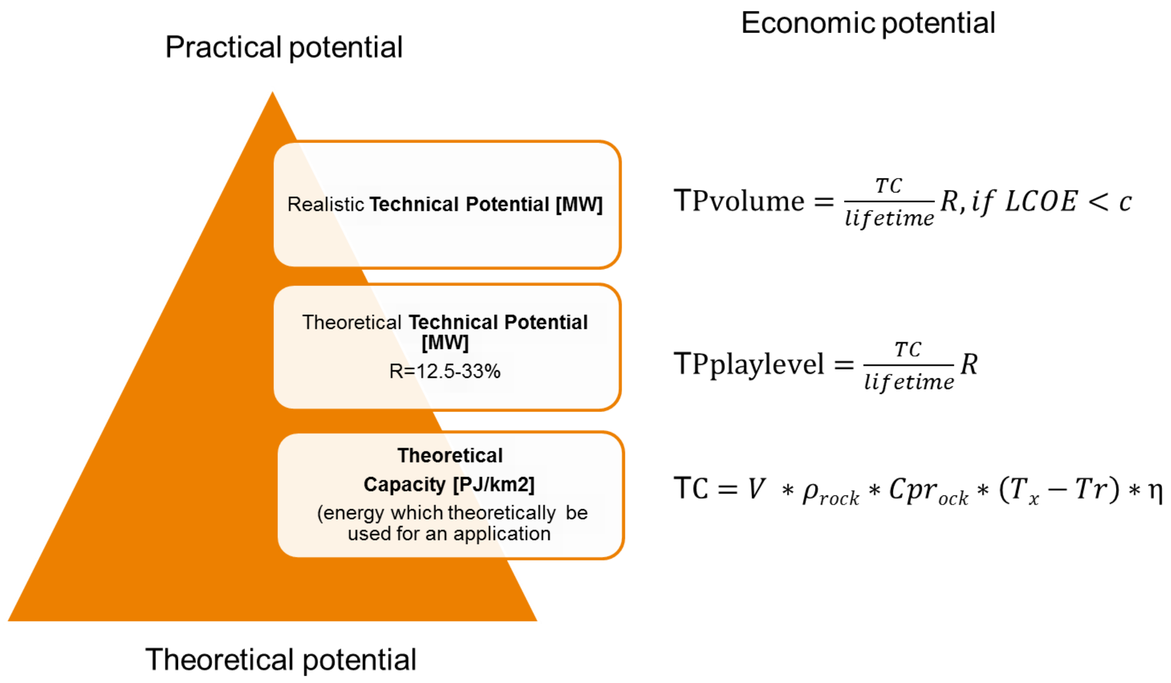

Figure 9: schematic workflow to go from theoretical capacity to realistic potential.

Table 1: potential maps calculated from the 3D voxet

parameter	Name	Unit
HIP	Heat in place	PJ/km2
TC	Theoretical capacity	PJ/km2
TPtheory	Theoretical Technical Potential (R=1)	MW/km2
TPbm	Technical Potential according to Beardsmore et al., 2010 (R=0.01)	MW/km2
TPreal	Technical Potential (R=0.125)	MW/km2
TPlcoe_p	Economic Technical Potential (LCOE<cutoff) at expectation p (0..100%)	MW/km2
LCOE_p	Levelized Cost of Energy	€/MWh (electricity)

heat in place (HIP): The heat in place is calculated as the heat energy available in the subsurface. The calculation for a subvolume V:

$$HIP\ [PJ] = V * \rho_{rock}\ c_{rock} * (Tx - Ts) * 10^{-15}$$

where

V=volume [m3] of the subsurface subvolume
ρ_{rock} = Density = 2500 kg m-3
C_{rock} = Specific heat = 1000 J kg-1 K-1
Tx = temperature at depth in the subvolume
Ts = temperature at surface

The map of HIP [PJ/km^2] is calculated as the vertical sum of the vertically stacked subvolumes divided over the surface area of the grid cells in km^2

Theoretical capacity (TC): the *theoretical capacity* [TC] is in agreement with the heat energy in place multiplied by an (electricity) conversion factor which depends on the application:

TC=H *η

Where

$H = V * \rho rock * Cprock * (Tx - Tr) * 10^{-15}$ (in PJ)

The heat in place also takes into account the fact that energy cannot be utilized up till the surface temperature. d a return temperature Tr is used, which equals the previously mentioned cut-off production temperature for the application. For electricity production, following beardsmore et (2010):
To obtain a Theoretical potential map the values in the 3D-grid are vertically summed.
For heat production Tr is significantly lower than for electricity production

Technical potential:
Technical potential denotes the expected recoverable geothermal energy [MW] (e.g. Williams et al., 2008). The technical potential (TP) assumes that the resource will be developed in a period of thirty years. The conversion from *Theoretical capacity* to *Technical potential* is therefore:

- TP [MW/km2] = 1.057* TC[PJ/km2] * R.

Where R is the recovery factor which is underlain by various steps, depending also on the delineation of the volume for the TC. For a global assessment, such as performed for chapter 4 on geothermal energy of the IPCC (2011) and Beardsmore et al. (2010), TP considers heat in place of all the sediments and crust beyond a threshold depth in agreement with a cutoff temperature for electricity production systems. In Beardsmore et al., 2010, the ultimate recovery (R) corresponds to:
$R = R_{av} R_f R_{TD}$,
and includes available land areas, limited technical ultimate recovery from the reservoir based on recovery of heat from a fracture network (R_f) and limitation of operations as an effect of temperature drawdown (R_{TD}). Globally this can result in a recovery of about 1% of the theoretical capacity (IPPC, 2011). The recovery factor of EGS as performed by Beardsmore et al. (2010) does not delineate the reservoir in depth beyond the threshold temperature. For a volumetric delineation which is based on particular play levels leads and prospects (e.g. an aquifer), the recovery factor is generally much higher in the order of 10-50%, whereas the underlying TC involves a significantly lower amount of rock volume.
We propose to use three different levels of TP:

- TPtheory: this is the maximum possible (theoretical) technical potential (R=1.00)
- TPreal: realistic underground Technical Potential according to typical predictive reservoir engineering approaches and empirical practice This is the equivalent of R_f*R_{TD} in Beardsmore et al., 2012. According to Beardsmore R_f is on average 0.14. R_{TD} is estimated at 90%, resulting in R=0.125. For geothermal aquifers in the Netherlands R is estimated to be 33%
- TPbm: Technical Potential according to Beardsmore et al., 2010 (R=0.01)

Economic technical potential: The economic potential (TPlcoe_p) is calculated from the TPreal, accepting only those subvolumes where the levelized cost of energy (LCOE) is less than a given threshold. The LCOE depend on the application (*power, power and co-heat*).. The economics takes as input the expected flowrate. In TPlcoe_p, p denotes the cumulative probability (0..100%) of exceeding the flowrate and temperatures used. The economic evaluation and underlying parameters are available in a spreadsheet (*annex 3)* and in the code. The economic evaluation considers the achievable flow-rate as major technical uncertainty

3.1.1 Required input

In order EU-27 voxet models with onshore temperatures at depth measured up till 7 and 10 km depth. Horizontal resolution is 10 km vertical resolution is 250 m. The underlying information is the following

Input:

1. Average surface temperature
2. Topography
3. Depth (from surface) of Basement sediment interface
4. Depth (from surface) of MOHO
5. Surface heat flow (Cloetingh et al., 2010)
6. Various temperature maps at depth of countries, complemented by temperature maps of the geothermal atlas (Hurtig et al., 1992) of 1 and 2 km depth
7. Map of lithosphere thickness (Cloetingh et al., 2010)

The information above is blended in a numerical model, which provides a mean value and uncertainty on temperature. The methodology is explained in a separate document which is released jointly with the potential maps

3.1.2 Uncertainty assessment – techno-economic scenarios

Uncertainty in the potential estimates is based on:

- Temperature assessment
- Flow rate assessment

Future scenarios (2020-2050) take into account various scenarios for technological improvement and reduction of costs

- Improvement of conversion efficiency
- Reduction of drilling costs
- Enhancing flow rates

The quantitative specification of these will be given at the release of the potential maps

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Annex 1: Information required for different play types

The following Level 2 play systems have been identified at this stage (Fig. 3, Fig. 11)
- Hot Sedimentary Aquifers (including pressurized and karstified)
- Magmatic areas
- Low permeable deep rocks

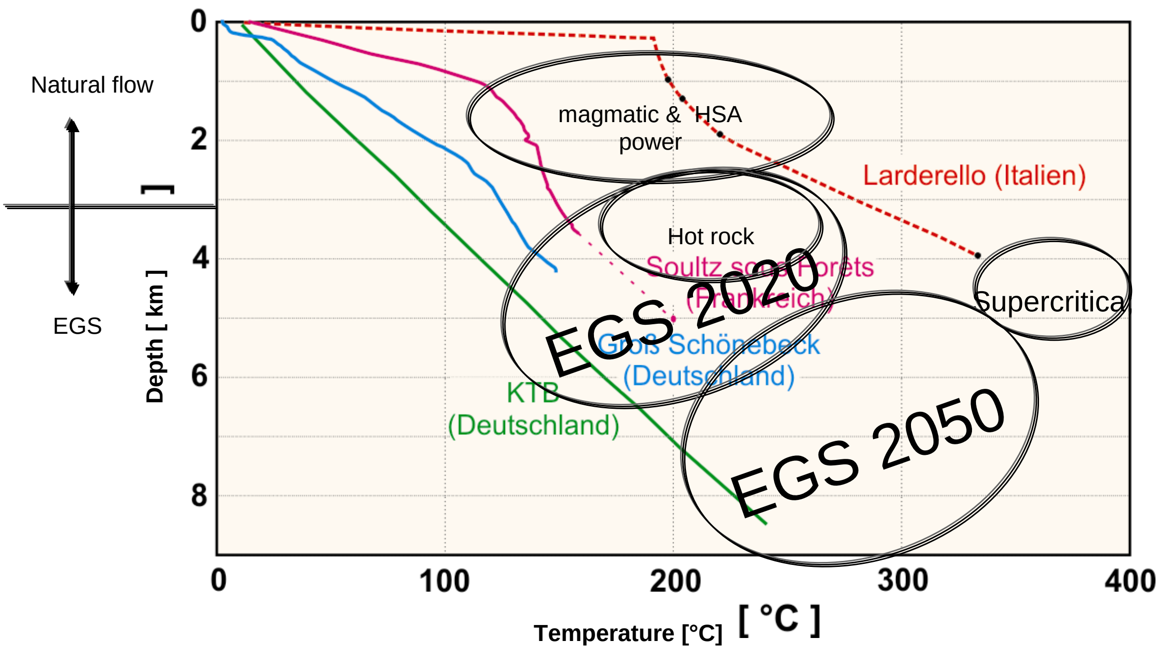

Figure: Relative positioning in depth and temperature gradients of the different play types, and positioning of EGS development (hot rock/EGS correspond to low permeable rock. HSA to hot sedimentary aquifers (which can also be located deeper up to 4km)

Hot sedimentary aquifers and magmatic plays can be mostly developed without enhancing the reservoir, relying on natural aquifer and fracture permeability. Magmatic plays can generally produce very high temperatures at shallow depth. Currently targeted low permeable rock plays are located in regions of elevated temperatures (caused by radiogenic heat production, elevated tectonic heat flow, or vertical heat advection trough deep fault zones). Low permeable rock plays are, typically situated in basement rock marked by relatively low natural permeability.

For each of these plays, the actual information which is required for resource assessment differs, and is outlined below.

Hot Sedimentary Aquifers (HSA)

This implies: karstified, undeep, and over pressurized aquifer rocks

<u>Criteria:</u>
- Not too deep (< 4 km) ➔ required: depth maps of the basin
- Lithology ➔ sedimentary, permeability through pores and natural fractures (karsts) → permeability data
- Permeability is reduced through mechanical compaction but can be retained through overpressure and natural fractures → pressure info

- Karst is dependent on geological history

relevant data from partners:

- Raster maps on outline of aquifers, in more detail depth, porosity, permeability, lateral extend of lithologic units which are potentially suitable
- Transimissivity or Porosity-Permeability measurements or concepts for poro-perm relationships and Porosity/depth relationship
- Overpressure data
- Indication of level of Seismic control and well data density for maps?
- Major faults

Exploration data on prospective resources (exploration data cf.. figure 9)

Assistance from GEOELEC:

- Assistance in evaluation of the natural permeability of aquifers
- Evaluation of the potential suitability of lithologic units

low permeable rocks suitable for EGS

This corresponds to relatively high temperatures in low permeable rocks. The origin can be related to vertical fluid flow conduits through large scale fractures and faults or to locally elevated thermal gradients due to thermal properties (e,.g. granite bodies).

Further particular tectonic settings may favour reservoir stimulation and the possible existence of natural pathways for high temperature fluids

Criteria for vertical and horizontal conduits along faults:

- Indications for flow conduits, e. g. thermal springs, thermal anomalies

Criteria for elevated heat flow and temperatures for granitic bodies

- Radiogenic heat production measurements
- Geometry of radiogenic bodies
- Indications for vertical flow conduits, e. g. thermal springs, thermal anomalies

relevant data :

- Outline of granite bodies (in depth, in map)
- Radiogenic heat production
- Major faults
- Stress and seismicity data

Exploration data on prospective resources (exploration data cf.. figure 9)

Assistance from GEOELEC:

- Feasibility evaluation concerning the faults' suitability for EGS operations
- Estimations regarding expectable flow rates
- Evaluation of rock stimulation potential
- Estimation of EGS potential

Magmatic areas

<u>criteria</u>

<u>high temperature</u>
<u>fluid flow convection possible</u>

<u>Supply data from partners:</u>

- volcanic regions
- surface temperature measurements
- thermal springs - geothermometers
- tomography
- base natural seismicity
- Major faults
- rock types (fractures, extent porous rocks e.g. tuffs)

Annex 2: Data Aquisition sheet

GEOELEC Data Acquisition Sheet

WP2: RESOURCE ASSESSMENT

Introduction

Below an abstract is provided from the GEOELEC Resource Assessment Protocol. In this protocol the methodology of resource assessment is described in more detail. It proposes adequate terminology and procedures for a Europe wide resource assessment.

The resource assessment protocol is based on resource assessment concepts developed in the oil and gas industry, which have been adopted in an adjusted form for geothermal resource assessment and reporting. This protocol has been based on the following work:

- Beardsmore et al., 2010. A protocol for estimating and mapping the global EGS potential.
- AGEA, 2010. Australian code for reporting of exploration results, geothermal resources and geothermal reserves: the geothermal reporting code
- CanGEA, 2010. The Canadian geothermal code for public reporting

For GEOELEC we envisage 3 levels of resource detailing (see chapter 3 in the Resource Assessment Protocol).

- Level 1: Global European prospective resource assessment for EGS
- Level 2: Prospective undiscovered resource assessment for different play types
- Level 3: Contingent (discovered) resources and reserves

In GEO-ELEC we aim to perform a global Level 1 assessment, complemented with some level 2 and level 3 information if easily available. The assessment and map information will be presented in a public web-based information system (cf www.thermogis.nl/worldaquifer) containing key maps and data, such as spatially resolved temperatures, complemented with some level 2 and level 3 information. The compiled maps will be made digitally available to data providers.

The information gathering for the assessment will be accomplished through data workshops. These data worksheets serve to compile available information

The responsibility of GEOELEC partners is to collect the data and decide what is considered to be useful and/or essential. So there is no guarantee that delivered data will be used. However, the (compilation of knowledge on relevant data) will be stored for possible future EU project funding, and could be well used as meta data information in web-based information system.

Data information sheet for LEVEL 1 and (partly) LEVEL 2

For the GEOELEC, we would kindly request you to fill in the questionnaire below. Note that the provider of the information is not responsible for the delivery of the information. However, the provider is requested to correctly report the source of the information.

It is further assumed that the owner of the data is responsible for storing and distributing the underlying data, or alternatively you may identify data or key publications which have originated from you or affiliated institutes

Digital = Database in any accessible form (*.xls, *.mdb, etc)
Paper = Either printed or in PDF
#... = Number of …

Please indicate whether the information provided is/will be publically available

---

1. Name of institute:
2. Country:
3. Contact person:
4. Contact details:

5. Known data of the temperature in the subsurface (e.g. oil and gas BHT/DST)
   a. #.... Uncorrected BHT data

      Publically available — Yes ☐ No ☐

      Data available on: — Digital ☐ Paper ☐

      (Internet) source location:

   b. #..... Corrected BHT data

      Publically available — Yes ☐ No ☐

      Data available on: — Digital ☐ Paper ☐

      (Internet) source location:

   c. #...... DST data

      Publically available — Yes ☐ No ☐

      Data available on: — Digital ☐ Paper ☐

      (Internet) source location:

6. Surface heat flow measurements and map interpretation
   a. # …. measurements

      Publically available — Yes ☐ No ☐

      Data available on: — Digital ☐ Paper ☐

      (Internet) source location:

   b. map coverage

      Publically available — Yes ☐ No ☐

      Data available on: — Digital ☐ Paper ☐

      (Internet) source location:

      …. % of country/ region name: …………

7. Thermal spring temperatures
   a. #.... springs (incl. temperatures when known)

	Yes	No
Publically available	☐	☐
	Digital	Paper
Data available on:	☐	☐

(Internet) source location:

8. High enthalpy data/interpretation in volcanic areas
   a. # … measurements (reservoir temperature)

	Yes	No
Publically available	☐	☐
	Digital	Paper
Data available on:	☐	☐

(Internet) source location:

9. Published temperature model interpretation (e.g. regional heat flow, local effects due to meteoric effects)
   a. Map coverage

	Yes	No
Publically available	☐	☐
	Digital	Paper
Data available on:	☐	☐

(Internet) source location:

…. % of country/ region name: …………………….

   b. Temperature at ……… km depth (can be more than 1)

	Yes	No
Publically available	☐	☐
	Digital	Paper
Data available on:	☐	☐

(Internet) source location:

   c. Heat flow at ... km depth (>3 km)

	Yes	No
Publically available	☐	☐
	Digital	Paper
Data available on:	☐	☐

(Internet) source location:

10. If applicable: basin layout and sediment-basement interface depth
    a. Basin contours

	Yes	No
Publically available	☐	☐
	Shape	Paper
Data available on:	☐	☐

(Internet) source location:

…. % of country/ region name: …………………….

    b. Sediment thickness

	Yes	No
Publically available	☐	☐
	Raster	Paper
Data available on:	☐	☐

(Internet) source location:

…. % of country/ region name: …………………….

11. If applicable: outlines of granitic formations:

    a. granite outlines

	Yes	No
Publically available	☐	☐
	Digital	Paper
Data available on:	☐	☐

(Internet) source location:

…. % of country/ region name: …………………….

    b. granite thickness (thickness map or 3 classes <3km, >3 km, >6km)

	Yes	No
Publically available	☐	☐
	Digital	Paper
Data available on:	☐	☐

(Internet) source location:

Stress likelihood of EGS

12. Fault mapping → Tertiary and Quaternary fault systems

	Yes	No
Publically available	☐	☐
	Digital	**Paper**
Data available on:	☐	☐

(Internet) source location:

13. Recorded seismicity

	Yes	No
Publically available	☐	☐
	Digital	**Paper**
Data available on:	☐	☐

(Internet) source location:

Restrictions on development

14. Information about geographical restricted areas for geothermal?
(Consider mining, oil exploration, CCS, nuclear storage, spa's, interference with drinking water, etc.)

	Yes	No
Publically available	☐	☐
	Digital	**Paper**
Data available on:	☐	☐

(Internet) source location:

15. Do you for see competitive planning of the subsurface? Yes ☐ No ☐

Please elaborate:

16. Information about surface restrictions for geothermal?
(Consider land slides, natural reserves, etc.)

	Yes	No
Publically available	☐	☐
	Digital	**Paper**
Data available on:	☐	☐

(Internet) source location:

Ongoing exploration licenses

17. Exploration and production licenses and (projected) power production

	Yes	No
Publically available	☐	☐
	Digital	**Paper**
Data available on:	☐	☐

(Internet) source location:

Level 2

Prospective undiscovered resource assessment for different play types: Identify delimited areas with a particular play type (Hot Sedimentary Aquifer (HSA), active faults, granites, magmatic convective). Include data relevant to exploration of particular play types and exploration outcomes (cf. AGEA-AGEC, 2010) for exploration data relevant to resources assessment

The following play systems have been identified at this stage

- Hot Sedimentary Aquifers (including pressurized and kartstified)
- EGS as partially enhancing natural permeability (active faults, low permeability aquifers)
- Granites (covered by sediments)
- volcanic naturally convective

What can you provide?

1. HSA → Raster maps on transmissivity, lateral extend of lithologic units which are potentially suitable
2. HSA → Porosity-Permeability measurements or concepts for poro-perm relationships_and Porosity/depth relationship, Overpressure data
3. Exploration data on particular data prospective resources
4. Which plays do you recon are present in your country
5. Who is, according to you, the entity or person who is on behalf of your country responsible for providing the data?

Level 3

Contingent (discovered) resources and reserves: From industry and government reporting obtain information on drilled prospects and producing reserves

At this stage no further data/information required.

Annex 3: techno-economic calculation sheet

The specification of the techno-economic evaluation is provided in an excel sheet which is distributed jointly with this document. The layout of the spreadsheet is given below. Exact details will be released jointly with the final potential maps.

Geothermal Energy			Operational choice	power

INPUTVARIABLES	used	Value	Unit	Comment
Flowrate	1	100	L/s	total flow rate which is achieved from the subsurface (measured at surface conditions)
along hole depth of a single well	1	5000	m	along hole depth (total length) of a single borehole in the subsurface
Surface temperature	1	17	C	average yearly surface temperature
production temperature (Tx)	1	172	C	production temperature (reservoir temperature, corrected for temperature losses)
Economic lifetime	1	30	Years	lifetime for cash flow calculations
subsurface				
well cost scaling factor	1	1	-	scaling factor for calculating well costs
well costs	1	9	mln euro/Well	calculated costs for drillling the wells
Stimulation and other Cost	1	0	mln euro/Well	additional well costs for stimulation (and other costs) of the reservoir
Pump investment	1	0.6	Mln euro/pump	pump investements. Workover is assumed every 5 years at installment costs
Number of wells	1	2	-	number of wells in the reservoir
subsurface capex	1	**18.1**	mln euro	calculated subsurface capex for wells, stimulation and pumps
subsurface parasitic				
COP	1	20	-	coefficient of performance (MWth/MWe) to drive the pumps. Ratio of thermal and electric power
electricity price for driving the pumps	1	110	euro /MWhe	electricity price for the power consumed by the subsurface pumps
Variable O&M	1	5.5	euro/MWhth	calculated variable O&M per unit of heat produced (1MWhth=3.6GJ)
power temperature range used				
(co) heat relative starting temperature	0	0%	%	relative value (100%= Tx,0%=Tbase) for upper limit of temperature range for heat
outlet temperature power plant (Toutlet)	1	97	C	upper limit of Temperature for (co)heat use
power surface facilities				
thermal power for electricity	1	**34.361**	MWth	net power produced, taking into account the relative efficiency recorded by operating binary and
electric power		4.346	MWe	net power produced, taking into account the relative efficiency recorded by operating binary and
power Loadtime	1	8000	hours/year	effective load hours in a year for electricity production
power Plant investment costs	1	3.000	mln Euro/MWe	costs for power conversion system
power Distance to grid	1	5000	m	distance for the connection to the power grid
power Grid investment	1	80	Euro/kWe	grid connection cost per unit of power installed
power Grid Connection Variable	1	100	Euro/m	grid connection cost per unit of distance
power plant capex	1	**13.886**	mln Euro	calculated capex for power plant and grid connection
power Fixed O&M rate	1	1%	%	O&M costs as percentage of caclulated capex for (sub)surface facilities
power Fixed O&M	1	32	kEuro/MWe	calculated O&M costs per unit of power installed
power Variable O&M	1	43.48548387	Euro/MWhe	calculated variable O&M costs (dependent on COP, and efficiency of conversion)
(co)heat surface facilities				
direct heat reinjection temperature(Treinject)	0	35	C	reinjection temperature (effective temperature range is Toutlet..Treinject)
direct heat production	0	0.000	MWth	heat production
direct heat load hours	0	5000	hours/year	effective load hours in a year for heat production
direct heat plant investment costs	0	150.000	kEuro/MWth	heat surface installation costs per unit of heat production
direct heat capex	0	**0.00**	mln Euro	calculate capex for heat production surface facilities
direct heat Fixed O&M rate	0	1%	%	O&M costs as percentage of caclulated capex for (sub) surface facilities
direct heat Fixed O&M	0	18	kEuro/MWth	calculated O&M costs per unit of heat production installed
direct heat Variable O&M	0	5.5	Eur/MWHth	calculated variable O&M costs (dependent on COP)
complementary sales				
complementary electricity sales	1	0.00	Euro/MWh	complementary revenues from electricity sales
complementary heat sales	1	0	euro/GJ	complementary revennues from heat sales
fiscal stimulus				
fiscal stimulus on lowering EBT	1	**no**	yes/no	apply fiscal stimulus on lowering earnings before tax (EBT) of the project developer
percentage of CAPEX for fiscal stimulus	1	0%	%	percentage of CAPEX which can be deducted from EBT
legal max in allowed tax deduction	1	0	mln Euro	legal maximum in tax benefit
NPV of benefit to project	1	0.0	mln Euro	effective benefit to project
Inflation	1	0%	%	inflation for costs and benefits in project cash flow
loan rate	1	6.0%	%	interest rate on debt
Required return on equity	1	9%	%	required return on equity
Equity share in investment	1	100%	%	share of equity in the effective investment
Debt share in investment	1	0%	%	share of debt(the loan) in effective investment
Tax	1	38.3%	%	tax rate for company
Term Loan	1	30	Year	number of years for the loan
Depreciation period	1	30	Year	number of years for depreciation (linear per unit of production)

POWER (power,co-heat)	used	Value	Unit
levelized cost of energy (LCOE)	1	176.46	Euro/Mwhe

HEAT SHEET (heat)		Value	Unit
levelized cost of energy (LCOE)	0	0.00	Euro/GJ

rock and fluid properties

parameter	Value	Unit
Cpwater	4250	J/kg K
ρwater	1078	kg/m3
Cprock	1000	J/kg K
ρrock	2700	kg/m3

power conversion

relative efficiency	0.6	-
total conversion efficiency	0.1265	-
offset for Tbase	80	C
Tbase (minimum Tx for power)	97	C

heat (cold) conversion

total efficiency	0.5	-