A Resource assessment protocol for GEO-ELEC

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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, which can be subdivided in different production systems (Table 1)

- Conventional power (>150°C)
- Engineered (or enhanced) geothermal systems (EGS, >100°C)

The listed temperatures are current lower limits for Flash technology and binary energy conversion technology. These should be considered as tentative and will depend strongly on the actual surface development strategy. Please bear in mind that higher resource temperatures are required to obtain sufficient power in the conversion process, as energy efficiency at these minimum temperature are no higher than 7 and 10% (MIT, 2006). Detailing surface technology is beyond the scope of this document, however these minimum temperatures will be used to delineate resources.

Table 1: exemplary application assumptions

Parameter \ application	Binary	Conventional
Minimum production temperature [°C]	100	150
Return temperature[1] [°C]	80	90
Energy conversion efficiency	7% of more	10% or more

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. This is a life document, which will be adjusted based on feedback from countries contributing to the Geo-ELEC resource mapping.

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, using the best practices of the oil and gas exploration and production as guide lines. As a next step in chapter 3 we define the guidelines for estimating theoretical and technical potential for engineered (or enhanced) geothermal systems (EGS) and high enthalpy systems in detail for different stages in the workflow (play, lead, prospect, contingent resources, reserves) for

[1] These are currently arbitrarily chosen and need refinement

different play types. Connected, we make a suggestion for data we need as input to for the resource assessment.

2 Basic definitions

mcKelvey (Fig. 1) and **project approach (Fig. 2):** Key to resource assessment and classification is the concept of the McKelvey diagram (Figure 1), and a project oriented approach (Figure 2) 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. 3): 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.

Theoretical and technical potential (Fig. 4): it is important to note that resource potential is expressed in terms of recoverable geothermal energy [MWe] (e.g. Williams et al., 2008), which is often referred to as technical potential (TP). The technical potential (TP) assumes that the resource will be developed in a period of thirty years. The calculation of the potential is performed through a scheme which is explained in Beardsmore et al. (2010). Their approach is based on a volumetric geothermal assessment (cf Williams et al., 2008), which can include monte-carlo calculations to incorporate the effects of uncertainty. In their approach, the *theoretical capacity* [TC] is in agreement with the heat energy in place multiplied by an electricity conversion factor. The conversion from *Theoretical capacity* to *Technical potential* is marked by an accumulative 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), TC considers heat in place of all the sediments and crust beyond a threshold depth in agreement with a cutoff temperature for electricity production systems (Fig. 4). In Beardsmore et al., 2010, recovery $R=R_{av}\,R\,R_{TD}$, and includes available land areas, limited technical ultimate recovery from the reservoir based on recovery of heat from a fracture network (R) and limitation of operations as an effect of temperature drawdown (R_{TD}). Globally this can result in a recovery of about 1% of the heat energy in place (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 much higher in the order of 10-50%, whereas the underlying TC involves a significantly lower amount of rock volume,and the TP should remain the same. 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 6,5 km for 2020 and one based on 10 km for 2050.

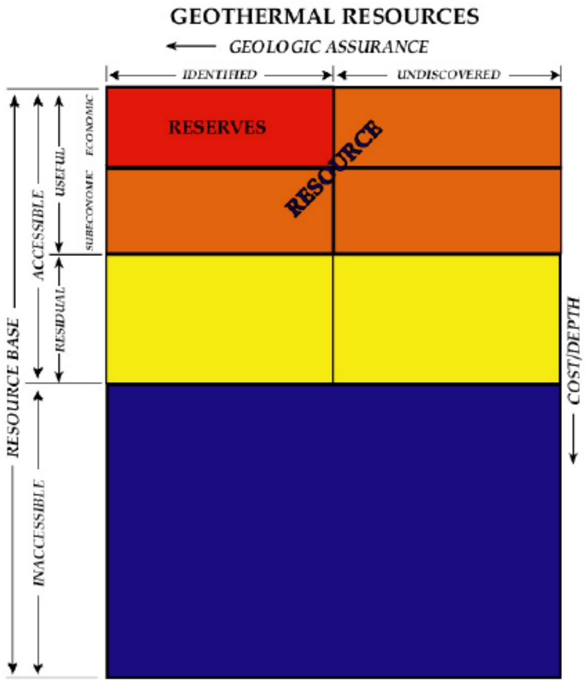

Figure 1: McKelvey diagram representing geothermal resource and reserve terminology in the context of geologic assurance and economic viability (from Williams et al., 2008))

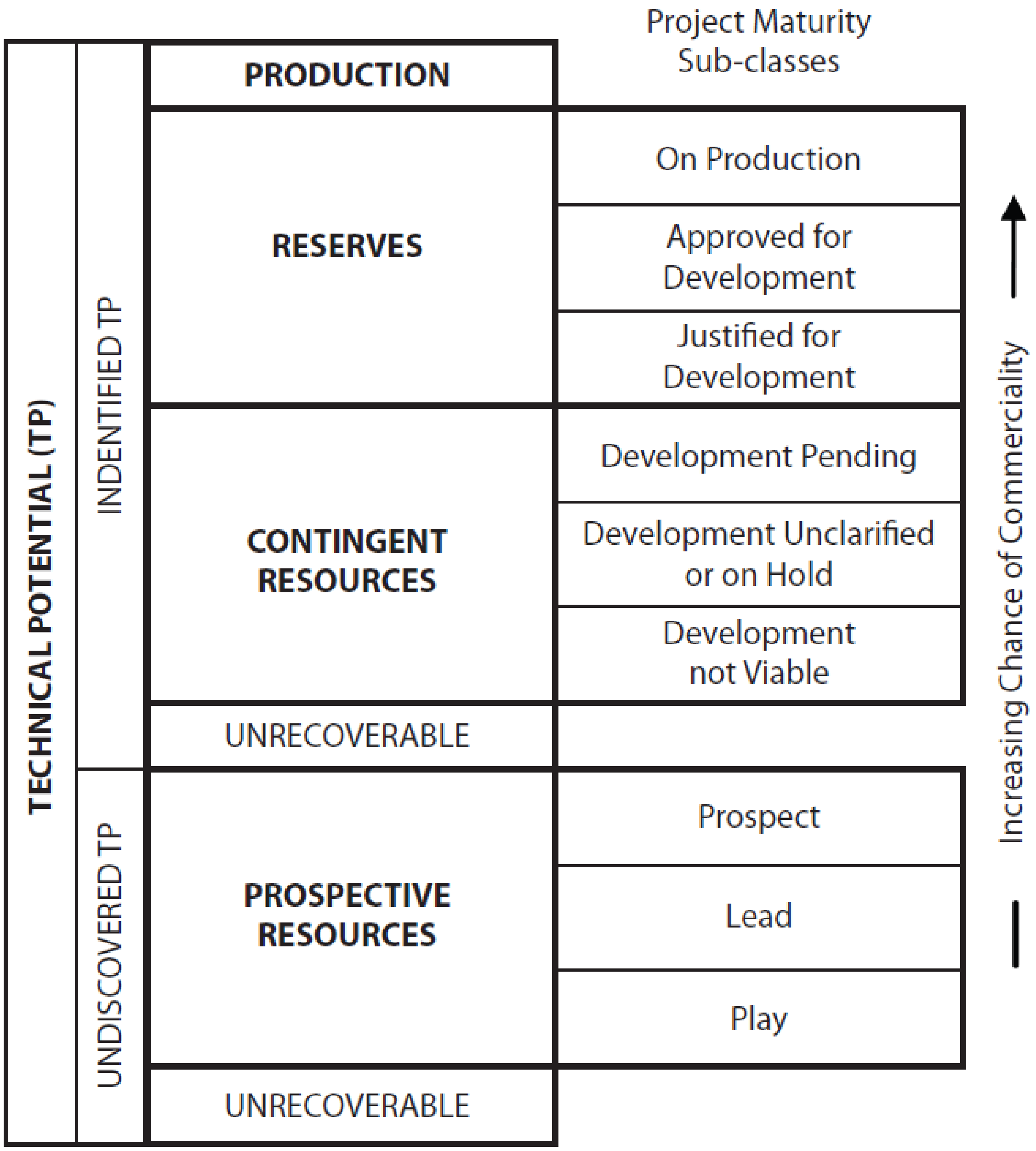

Figure 2: Project workflow oriented resource classification. Through the workflow undiscovered resources progressively develop into reserves (from Etherington and Ritter, 2007, modified by TNO, 2010). In oil and gas, the "technical potential" (TP) in the classification is referred as „total petroleum initially-in-place" (PIIP), which in geothermal terms could refer to theoretical capacity (TC) as used by IPPC(2011), expecially in the scope of EGS where manmade reservoirs can e created at virtually any depth beyond a threshold temperature. However, resources and reserves are estimated in recoverable quantities and reported based on (expected) ultimate recovery, which therefore corresponds to the technical potential TP. We have chosen to refer to TP instead of TC because of the analogon with referring to a particular geothermal play,

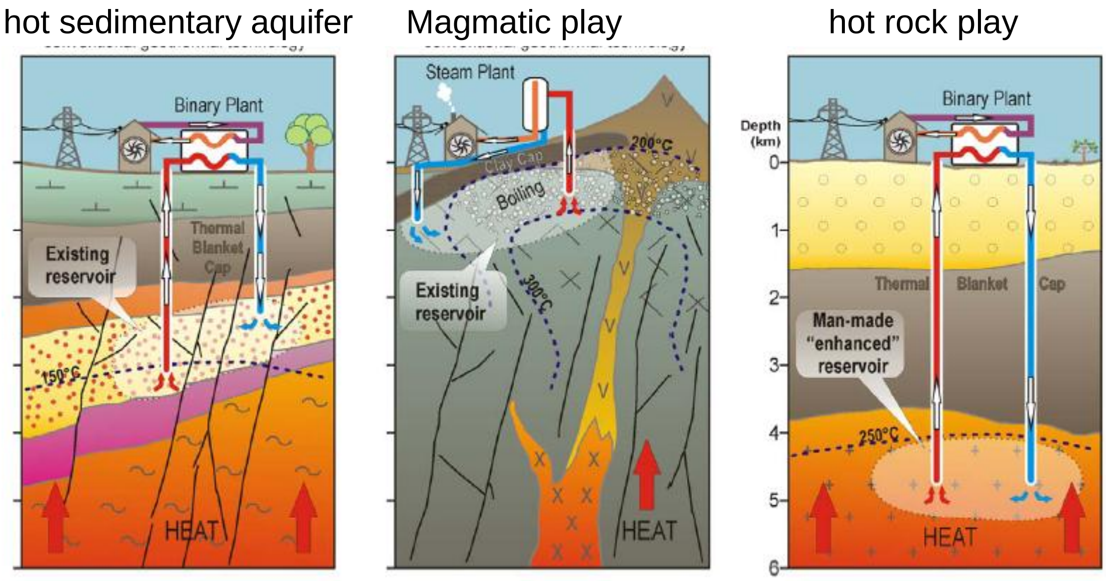

Figure 3: example of different play types for geothermal systems (modified from Hot Rock ltd). Hot sedimentary aquifers and magmatic plays can be mostly developed without enhancing the reservoir, relying on natural aquifer and fracture permeability. Magmatic plays can generally produce very high temperatures at shallow depth. Hot 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). Hot rock plays are, typically situated in basement rock marked by relatively low natural permeability.

1. Grid geographic region in 5' x5´ cells (approximately 5x5 km)	Each cell becomes a node in the regional resource estimate. A temperature vs depth profile to 10 km depth will be derived for each cell.
2. Determine temperature field	Determine temperature field from surface heat flow, surface temperature, thermal properties, borehole temperatures and tectonic setting. Start from published maps on temperature at depth. Progressively include recent country temperate assessment, where available and aim to include more recent strategies for temperature at depth following Cloetingh et al., 2010 and Davies and Davies, 2010
3. Determine theoretical potential for depth intervals with temperature exceeding 100°C and 150°C respectively	From temperature model derive amount of theoretical power in node [Mwe] for a number of depth intervals for binary (>100°C) and conventional power systems (>150°C?).Use best practice on energy conversion following Beardsmore et al., 2010.
4. Determine technical potential for depth intervals with temperature exceeding 100°C and 150°C respectively	Convert theoretical power to technical power adopting a reasonable recovery factor, reflecting the probability of achieving high enough productivity (flow rate). The recovery for global assessment is in the order of 1%. For specific prospects, leads or plays the recovery factor typically varies from 10-50%. An estimate of recovery factor for undiscovered resources should include the probability that the resource maybe unrecoverable.

Figure 4: schematic workflow to go from heat energy in place to recoverable (technical) resource potential (cf.simplified from Beardsmore et al., 2010). The actual workflow for a European assessment is outlined in more detail in chapter 3.

2.1 The hydrocarbon best practice and relation to geothermal energy

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. In the classification, 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. While five years is recommended as a benchmark, a longer time frame may be applied where, for example, development of economic projects are deferred at the option of the producer for, amongst other things, market-related reasons, or to meet contractual or strategic objectives.

Project Status and Commercial Risk

In order to establish a more detailed resources reporting system that can also provide the basis for portfolio management, the commerciality axis may be further subdivided according to Project Maturity (Fig. 2). Projects may be characterized by standard sub-classes and/or quantitative estimates of their chance of reaching producing status. Project Maturity reflects the actions (business decisions) required to move it towards commercial production.

Once projects satisfy commercial risk criteria, the associated quantities are classified as Reserves. These quantities may be allocated to the subdivisions based on the development and producing status of wells, associated facilities, and reservoirs. These Reserves Status modifiers (Developed Producing, Developed Non-producing and Undeveloped) are well defined by publications of the Society of Petroleum Engineers (SPE). Reserves Status has been traditionally applied to Proved Reserves only but these same modifiers may be used for all Reserves categories; even Proved Developed Producing estimates have a range of uncertainty. Quantities may be subdivided by Reserves Status independent of sub-classification by Project Maturity. If applied in combination, Developed and/or Undeveloped Reserves quantities may be identified separately within each Reserves sub-class. Projects may be further characterized by their Economic Status. All projects classified as Reserves must be economic under defined conditions. However, based on assumptions regarding future conditions and their impact on ultimate economic viability, projects currently classified as Contingent Resources may be broadly divided into two subgroups:

- Marginal Contingent Resources are associated with technically feasible projects that are currently economic, or projected to be economic with reasonably forecast improvements in conditions, but are currently not committed for development.
- Sub-Marginal Contingent Resources are those discoveries for which there is insufficient information to clearly define a recovery plan, or analysis indicates that portions of the discovery, although technically feasible to recover, could not be economically developed under reasonably forecast improvements in conditions.

Where evaluations are incomplete such that it is premature to clearly define ultimate chance of commerciality; it is acceptable to note that project economic status is "undetermined". Additional economic status modifiers may be applied to further characterize recoverable quantities; for example non-sales (e.g. flare and losses) may be separately identified and documented in addition to sales quantities for both production and recoverable resource estimates. Those discovered in-place volumes for which no technically feasible development projects are defined are classified as Unrecoverable.

Economic Status may be identified independently of, or applied in combination with, Project Maturity sub classification to more completely describe the project and its associated resources.

Resource Categorization

Resources estimates in any class or sub-class may be categorized according to the certainty of their recovery. These estimates have several sources of uncertainty:

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 (Fig. 5), a low, best, and high estimate shall 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.

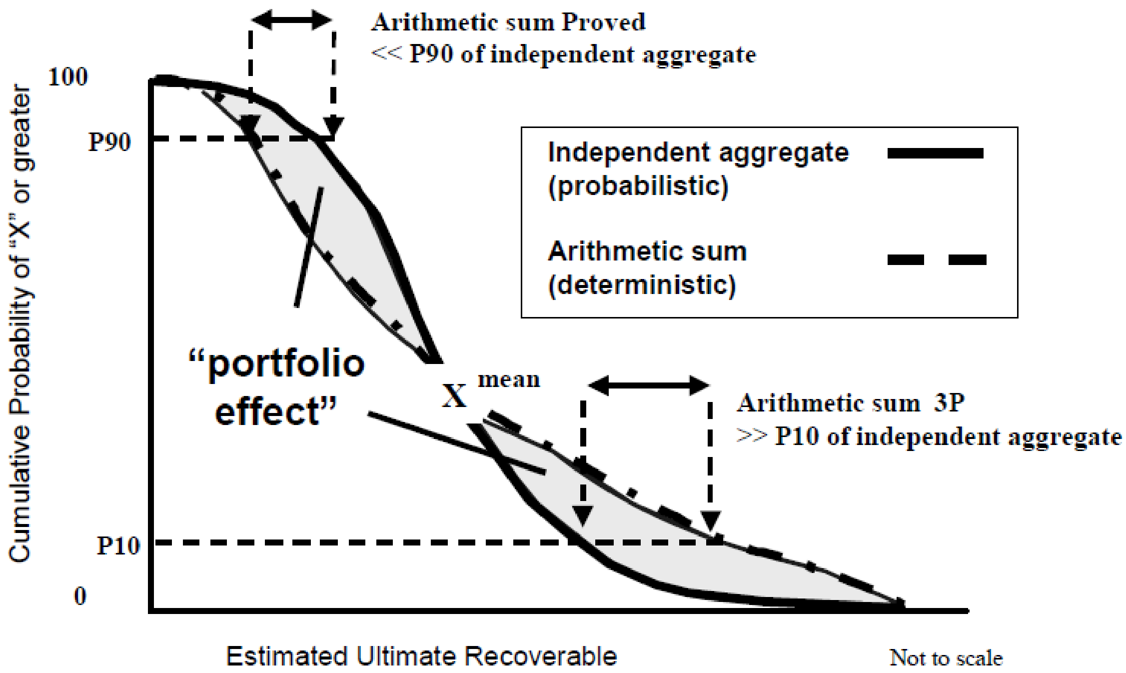

Figure 5: Expectation curves for estimating the cumulative resources in a portfolio taking into account uncertainty (from Etherington and Ritter.,2007)

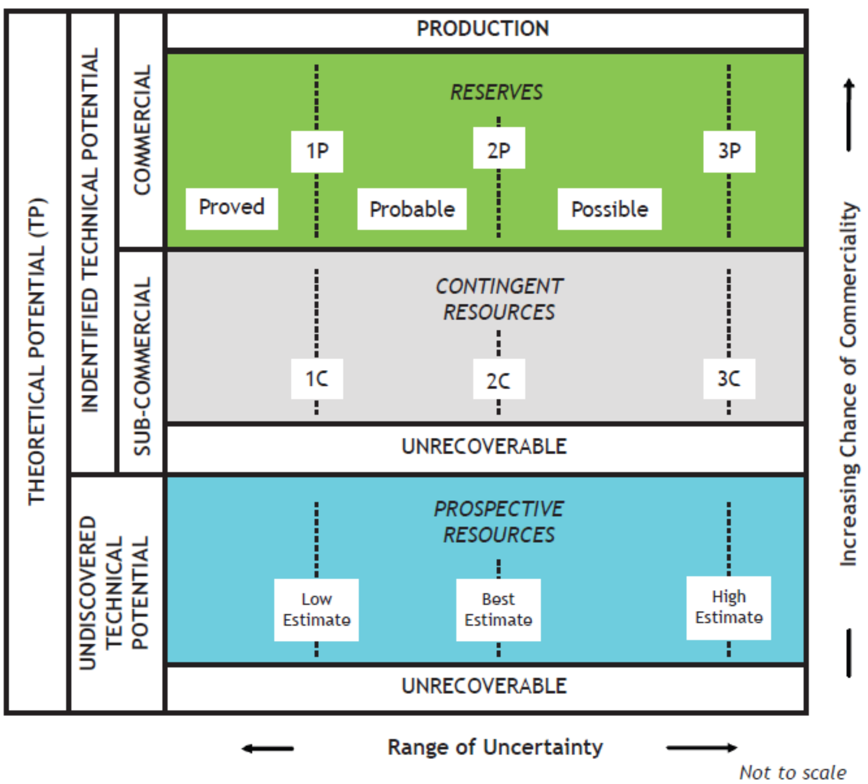

Figure 6: Geothermal Resource classification,including uncertainty ranges for resource and reserves estimates..

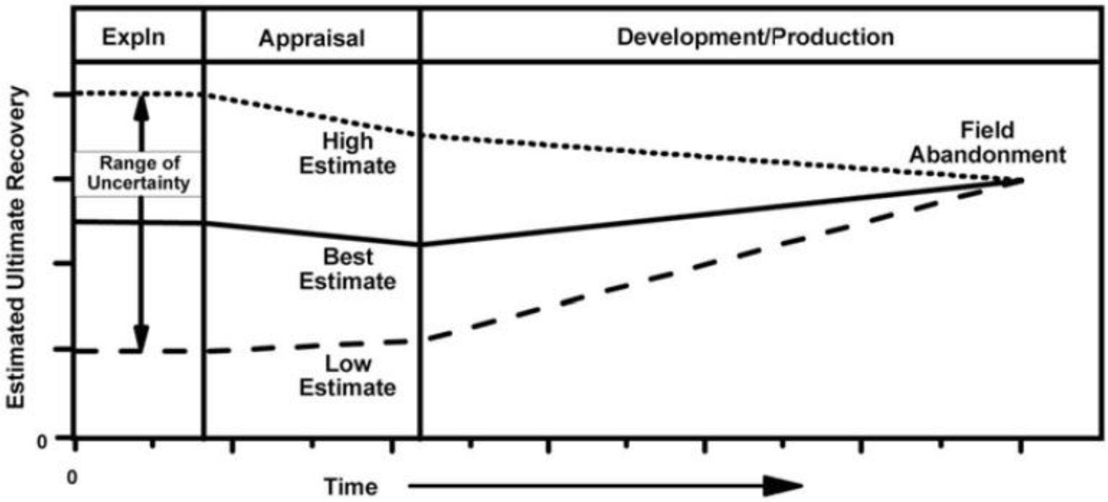

Figure 7: principle of funneling uncertainty over the project lifetime (from ???)

2.2 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 3):

- 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 resources and reserves, if publically available.
For GEO-ELEC this code can be well used (especially Table 1 therein, here figure 9), however with following remarks:

- The code does not take into account pre-existing subsurface data, which in mature oil and gas provinces in significant parts of Europe is of huge importance
- GEO-ELEC targets resources prior to selecting specific project locations

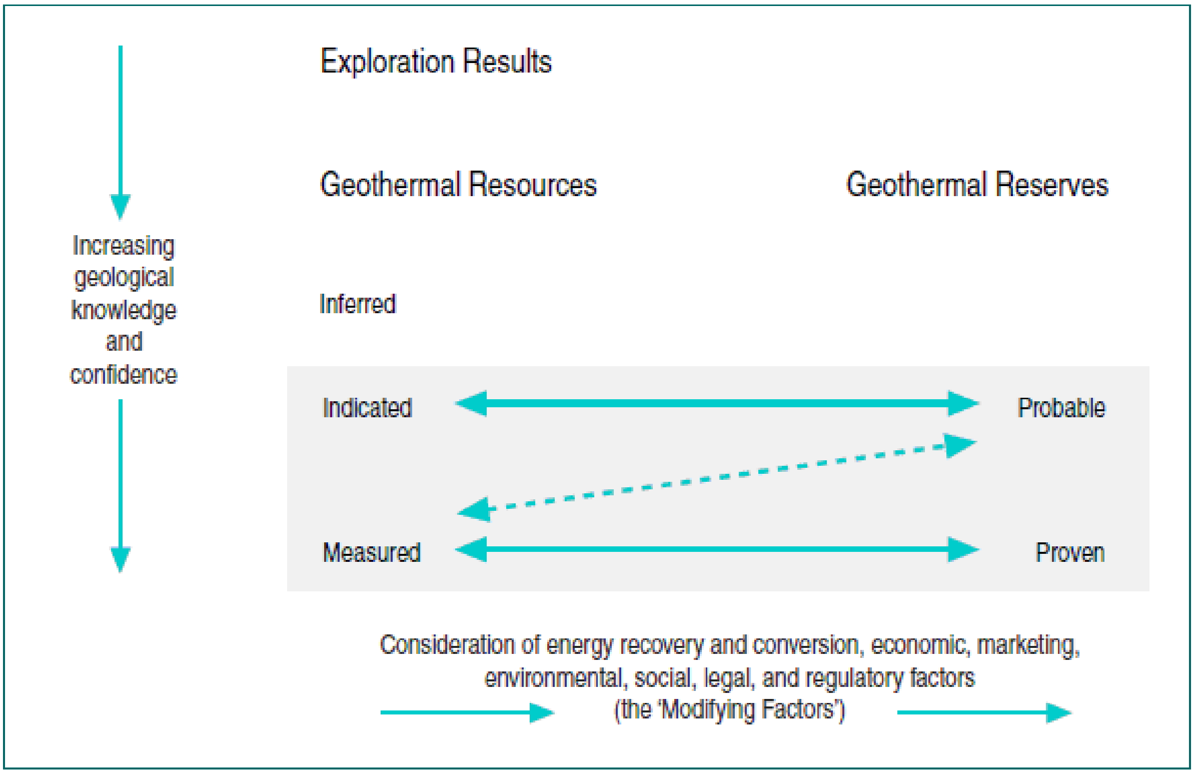

Figure 8. Categories of geothermal resources and reserves after the Australian Geothermal Reporting Code (from AGEA-AGEC, 2010)

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 9: classification of resources and reserves (from AGEA-AGEG, 2010)

3 Proposed resource assessment in GEO-ELEC

The resource assessment to be presented in GEO-ELEC is preferential subdivided in three levels (Figure 10):

- 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

1. Global European prospective resource assessment for EGS	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), EGS (previous), 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
3. Contingent (discovered) resources and reserves	From industry and government reporting obtain information on drilled prospects and producing reserves, play types, development type[2]

Figure 10: 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 GEO-ELEC we aim to perform a global Level 1 assessment, complemented with some level 2 and level 3 information if easily available and easy to incoporate. 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 information gathering for the assessment will be accomplished through data workshops. And a data request sheet (At these workshops information the resource protocol outline will be discussed and through a data-aquistion sheet which is included as appendix 1.

[2] 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 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.

Below we give more background information on public and additional information we envisage to be relevant for resource assessment, and our ideas on how to incorporate them in the assessment. In more detail requested data is outlined in the data request sheet in appendix 1

3.1 Global European prospective resource assessment, including EGS

The first level is a global European assessment of geothermal electricity potential in Europe at time horizons of 2020 and beyond. This follows a global assessment strategy (cf.. Figure 4) at 5x5 km nodes, which does not identify particular play systems and considers 1% recovery through development of conventional power and EGS resources (cf. IPCC, 2011).

We will start with maps we can generate from public sources, augmented with information contributed by partners and participants to workshops:
The must have information is focused towards establishing the temperature field, which will be represented by temperature depth maps at depth intervals of 1 km up to a depth of 10km :

- Temperature field, based on:
  - Geothermal atlas (Hurtig et al., 1992) and European heat flow (Cloetingh et al., 2010), Davies and Davies (2010), International HF commission, extrapolation to greater depth
  - Country improvements through bore hole temperatures, surface heat flow measurements and thermal properties and country temperature models
- Average surface temperature
  - From NASA
  - From ThermoMap European project results
  - More detailed from country information if available

The recovery factor is default 1%, spatial differentiation of technical recovery can be based on level 2 specific play information (see below) and scope for development based on fraccebility and surface restrictions..At a global level1 we consider as nice to have:

- Restricted areas for geothermal (high population density, natural reserves, subsurface use for other purposes – oil/gas)
- Natural stress field , seismicity, and major Tertiary and Quarternary faults → influences fraccebility/induced seismcity
  - World stress map, public seismicity catalogues, higher local databases are very much appreciated
- Sediment basement interface (depth) and basin outlines
  - Influence fraccebility and regions for natural permeability and recovery factor.

Using the this information, resource assessment will involve at least 2 different surface development scenarios (binary and flash, cf Table 1) and aims to differentiate in terms of subsurface development in either EGS or natural flow, based on particular play type (cf Fig.11).

3.2 Prospective undiscovered resource assessment 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
- hot rock

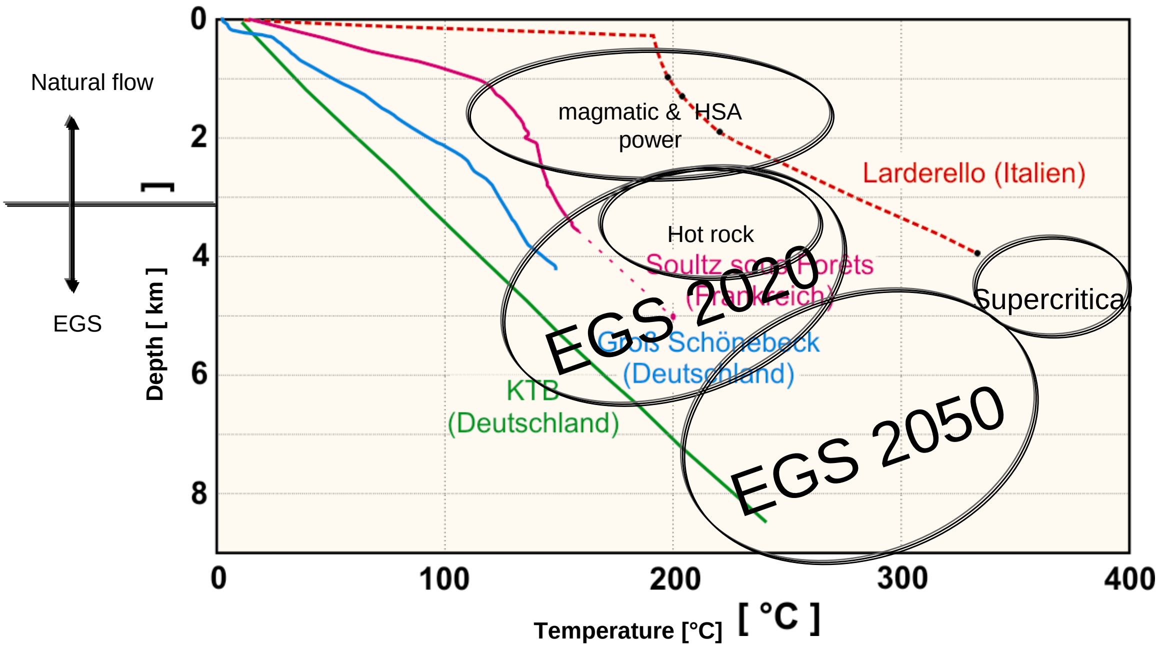

Fig. 11. Relative positioning in depth and temperature gradients of the different play types, and positioning of EGS development

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. Hot 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). Hot 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.

3.2.1 Hot Sedimentary Aquifers (HSA)

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

Criteria:

- 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?

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

3.2.2 hot rock suitable for EGS

This corresponds to relatively high temperatures in non-porous (no aquifers) and non magmatic 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). Recenctly active (Tertiary and Quaternary) favour the presence of natural pathways. . In particular the existence of faults, which have been active during the Tertiary and quanternary are considered indicative for such settings.

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

Criteria for vertical conduits along faults:

- Faults in questions have been active during since the Tertiary or Quaternary
- Indications for vertical 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
- Tertiary and Quaternary faults

- Natural seismicity
- 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 fraccebility
- Estimation of EGS potential

3.2.3 Magmatic areas

criteria

high temperature
fluid flow convection possible

Supply data from partners:

- volcanic regions
- surface temperature measurements
- thermal springs - geothermometers
- tomography
- base natural seismicity
- zones of active faults relays and vertical fluid flow conduits
- rock types (fractures, extent porous rocks e.g. tuffs)
- geochemistry (not to aggressive, CO_2 content etc)

4 Bibliography

AGEA-AGEG, 2008. Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves, The Geothermal Reporting Code, 2008 Edition, 26 p.

AGEA-AGEG, 2010. Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves, The Geothermal Reporting Code, Second Edition, 28 p.

Beardsmore, G.R., Rybach, L., Blackwell, D., and Baron, C., 2010. A protocol for estimating and mapping the global EGS potential, July 2010 edition, 11 p.

CanGEA, 2010. The Canadian Geothermal Code for Public Reporting, Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves, 2010 Edition, 32 p.

Cloetingh, S., v. Wees, J.D., Ziegler, P.A., Lenkey, L., Beekman, F., Tesauro, M., Förster, A., Norden, B., Kaban, M., Hardebol, N., Bonté, D., Genter, A., Guillou-Frottier, L. Voorde, M.T., Sokoutis,, D. Willingshofer, E., Cornu, T., and Worum, G., 2010. Lithosphere tectonics and thermo-mechanical properties: An integrated modelling approach for Enhanced Geothermal Systems exploration in Europe. Earth-Science Reviews, vol. 102, p. 159-206.

Davies, J.H. and Davies, D.R., 2010. Earth’s surface heat flux. Solid Earth, 1, 5–24.

Etherington, J.R., and Ritter, J.E., 2007. The 2007 SPE/AAPG/WPC/SPEE Reserves and Resources Classification, Definitions, and Guidelines: Defining the Standard!, 2007 SPE Hydrocarbon Economics and Evaluation Symposium, Dallas, Texas, USA, 1-3 April 2007. SPE 107693, 9 p.

Hurtig, E., Cermak, V., Haenel, R., and Zui, V.(eds.), 1992. Geothermal Atlas of Europe, International Association for Seismology and Physics of the Earth's Interior, International Heat Flow Commission, Central Institute for Physics of the Earth, Scale 1:2,500,000.

IPCC, 2011. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation – Geothermal Energy, Intergovernmental Panel on Climate Change (IPCC), Working Group III – Mitigation of Climate Change, 50 p.

Williams, C.F., Reed, M.J., and Mariner, R.H., 2008. A Review of Methods Applied by the U.S. Geological Survey in the Assesment of Identified Geothermal Resources, U.S. Department of the Interior, U.S. Geological Survey, Open-File Report 2008-1296, 27 p.

Williams, A.F., Lawless, J.V., Ward, M.A., Holgate, F.L., and Larking, A., 2010. A code for geothermal resources and reserves reporting, Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April 2010, 7 p.

World Petroleum Council, xxxx. Petroleum Resources Managment System, SPE-AAPG-WPC-SPEE, 47 p.

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