Methodology for Geothermal Ressource Assessment

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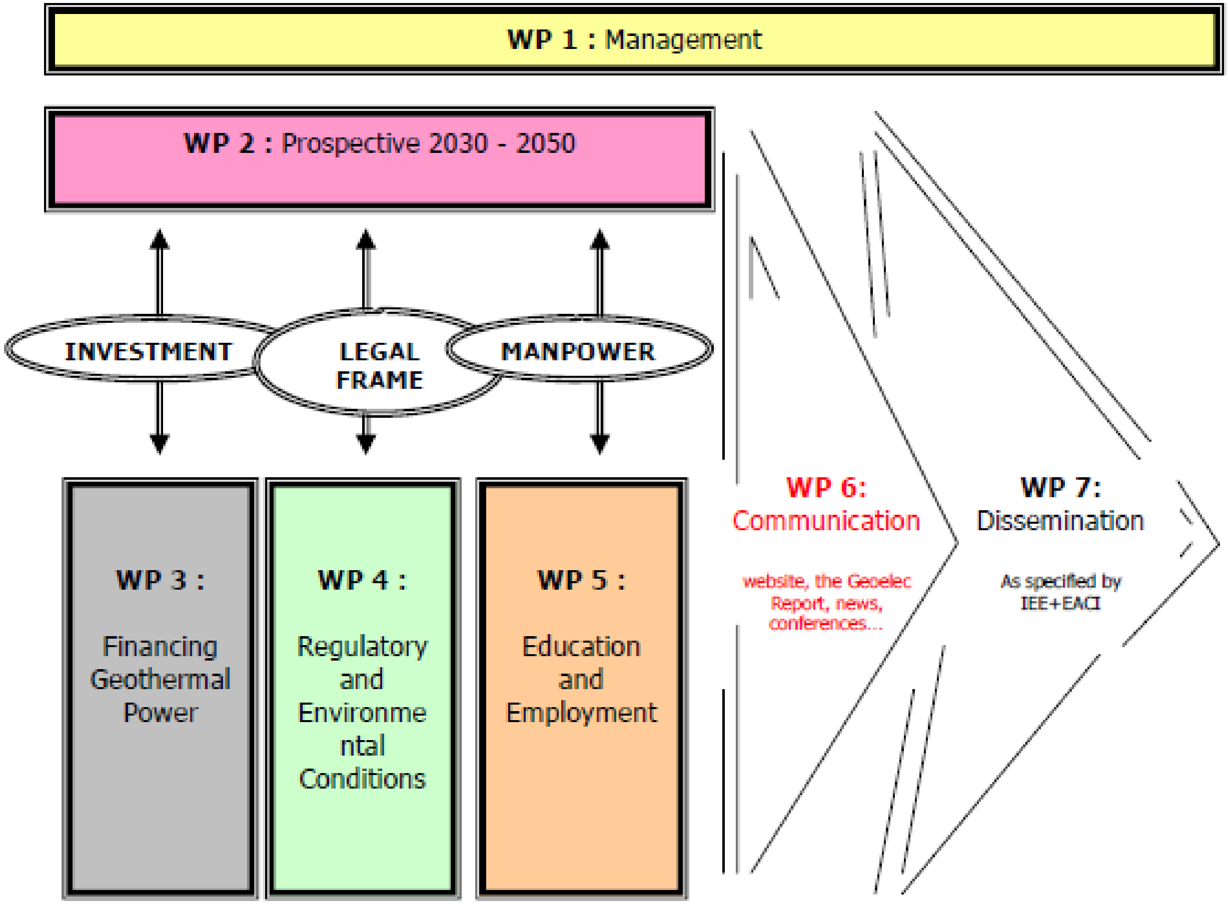
Embedding WP2 into GEOELEC



Partners

and EU-27 countries

Partner organisation	Task(s) for this partner organisation	Related to Task N°
TNO	WP lead Assessment and data compilation Forecasts for NL, BE, LU, DK, SE	1-2-3 1 3
EGEC	Data compilation Forecasts for UK, IE, FI, EE, LT, LV, CZ	1 3
BRGM	Assessment and data compilation Forecasts for FR	1-2 3
CRES	Data compilation Forecasts for EL, CY, ML, BG, RO	1-2 2-3
IGG CNR	Assessment Grid Forecasts for IT, SI	1 2 3
APPA	Data compilation Forecasts for ES, PT	1 3
GGSC	Data compilation Analyse Electricity demand	1 2
EnBW + Univ. Stuttgart	Data compilation Analyse Electricity demand Grid Forecasts for DE	1 2 3
Mannvit	Assessment Grid Forecasts for IS, HU, SK	1 2 3
GFZ	Data compilation Forecasts for DE, PL, AT	1 3

Tasks of WP2

- 1) Resource assessment: energy supply side
- 2) Electricity demand and grid infrastructure: the demand side
- 3) Forecasts and prospective (➔ links supply and demand)

Task 2.1

- Four actions:
  - A) Adopt a methodology for resource assessment
  - B) EGS resource classification (BRGM, TNO, APPA)
  - C) Data compilation and dissimination
  - D) Web-based GIS

What is resource assesment in context of Geo-ELEC

Fitting to the aim of Geo-ELEC

- Build resource assessment of Europe for geothermal power
- Time horizons of 2020 and beyond

- Build on extisting methodologies
- Proposed assessment methodology
- Presentation on pan-european scale

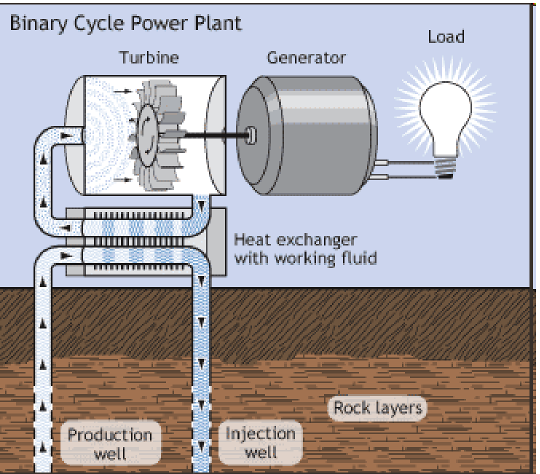
What do we need to do

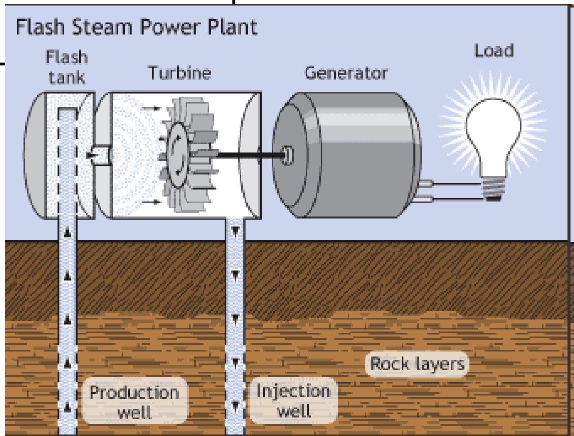
- Regional assessment
- Focus on suitable subsurface conditions

- Generalize development options
  - Surface (e.g. binary vs flash)
  - Subsurface development (EGS or not)

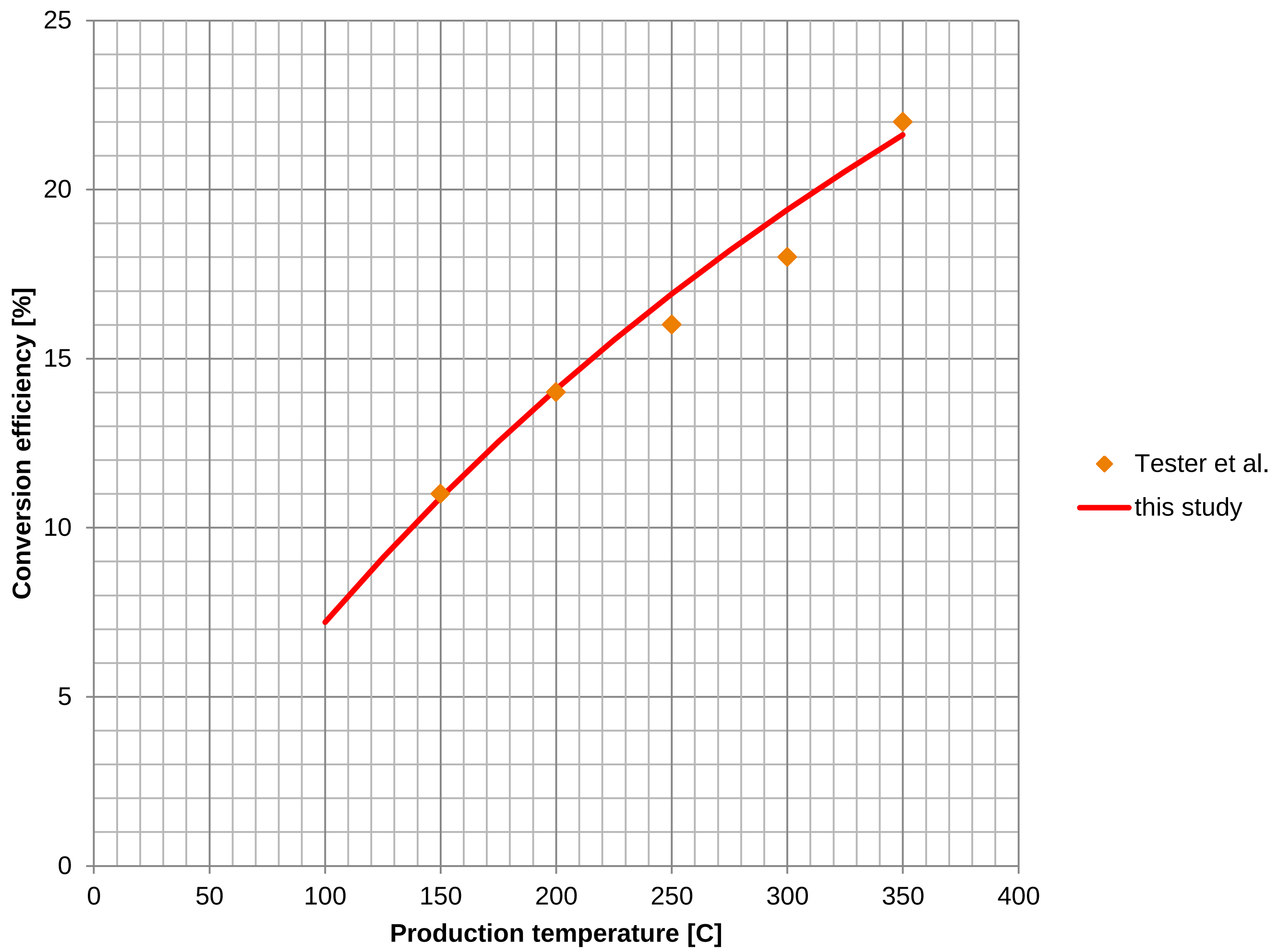
Suitable subsurface conditions for power production – binary and conventional

Parameter \ application	Binary	Conventional (steam/flash)
Minimum production temperature [°C]	100	150
Return temperature [°C]	80	90
Maximum production depth [km]	10	10
Energy conversion efficiency	7% or more	10% or more

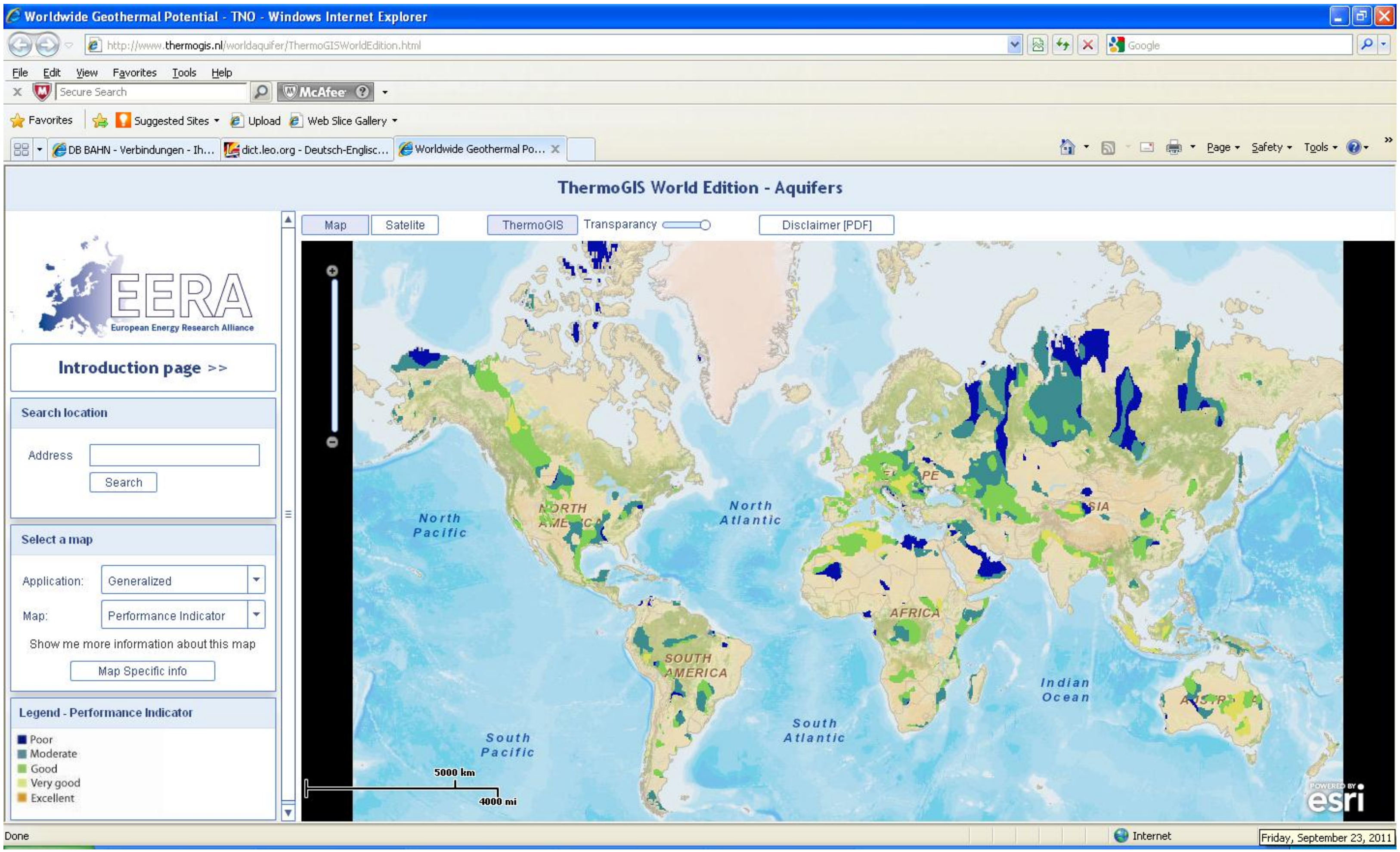




Figures: US DOE

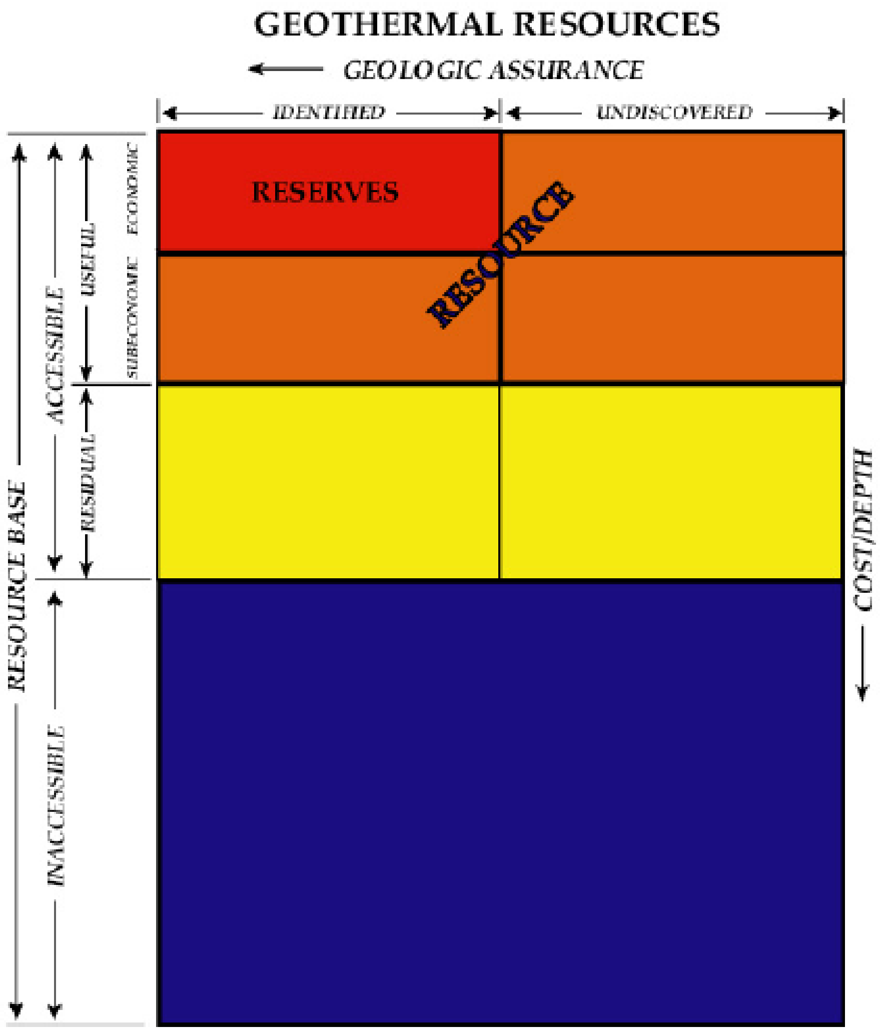

Conversion efficiency [%]
0
5
10
15
20
25
0
50
100
150
200
250
300
350
400
Production temperature [C]
Tester et al.
this study

WEB-GIS Application: EERA Thermogis World Edition



What is natural resource assessment

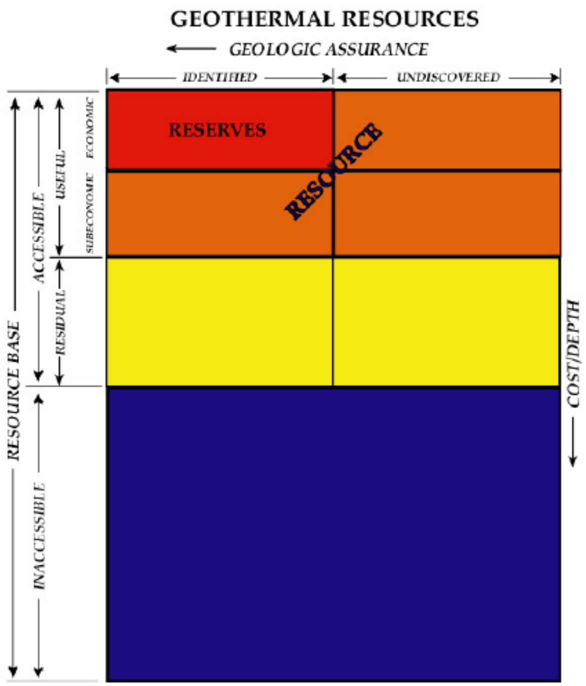
- **Quantitative assessment of accessible and useful earth system resources, subdivided in:**
  - **Reserves** which are demonstrated economically recoverable
  - **Resources** are possible future reserves, subdivided in
    - *Identified* or contigent
    - *Undiscovered* or prospective



McKelvey diagram (Williams et al., 2008)

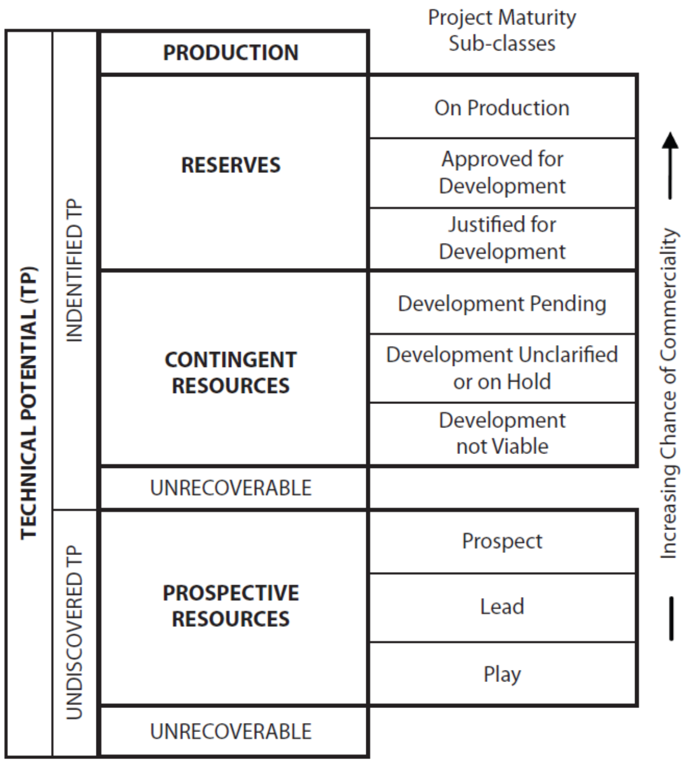
Resources are developed in Exploration workflow: prospective resources → Contigent resources → Reserves

Situational scheme



McKelvey diagram (Williams et al., 2008)

Project oriented scheme



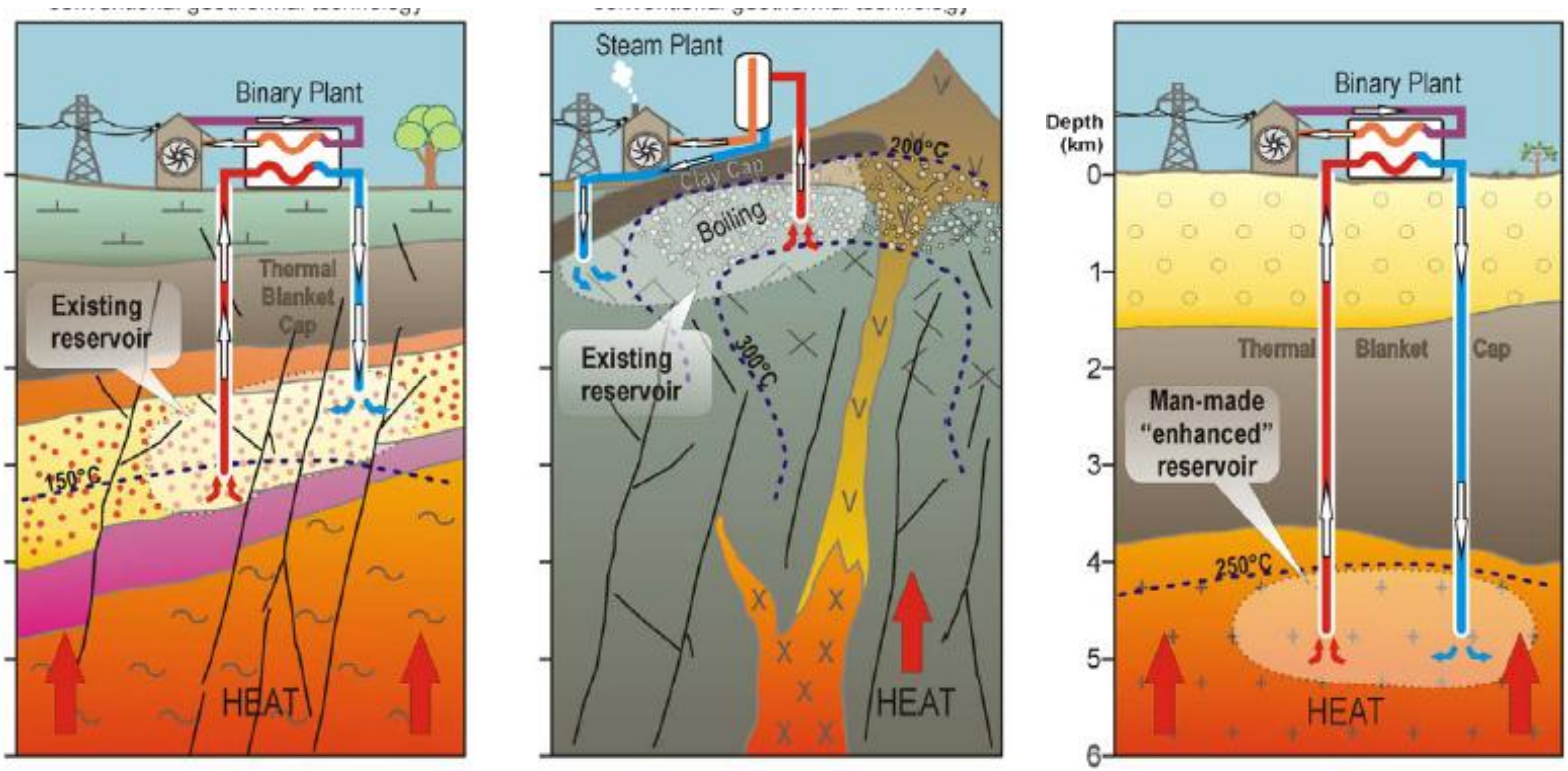
Project workflow (modified from Etherington & Ritter, 2007)

A bit more definition: Play, Leads and Prospects

- **Project phases**
  - Play ➔ Lead ➔ Prospect ➔ Drilling ➔ Production
- **Play**
  - Spatial (geographically / in depth) delimited area
  - Specific subsurface conditions which allow
    - Sufficient flow rate
    - Sufficient T
    - Suitable P and chemical conditions
- **Lead**
    - Discrete subsurface reservoir
    - Identified by surface exploration
- **Prospect**
  - Reservoir being studied thoroughly by surface exploration
  - Earmarked to be drilled

Looking at the subsurface resources: Play Types for power production

hot sedimentary aquifer | Magmatic play | hot rock play

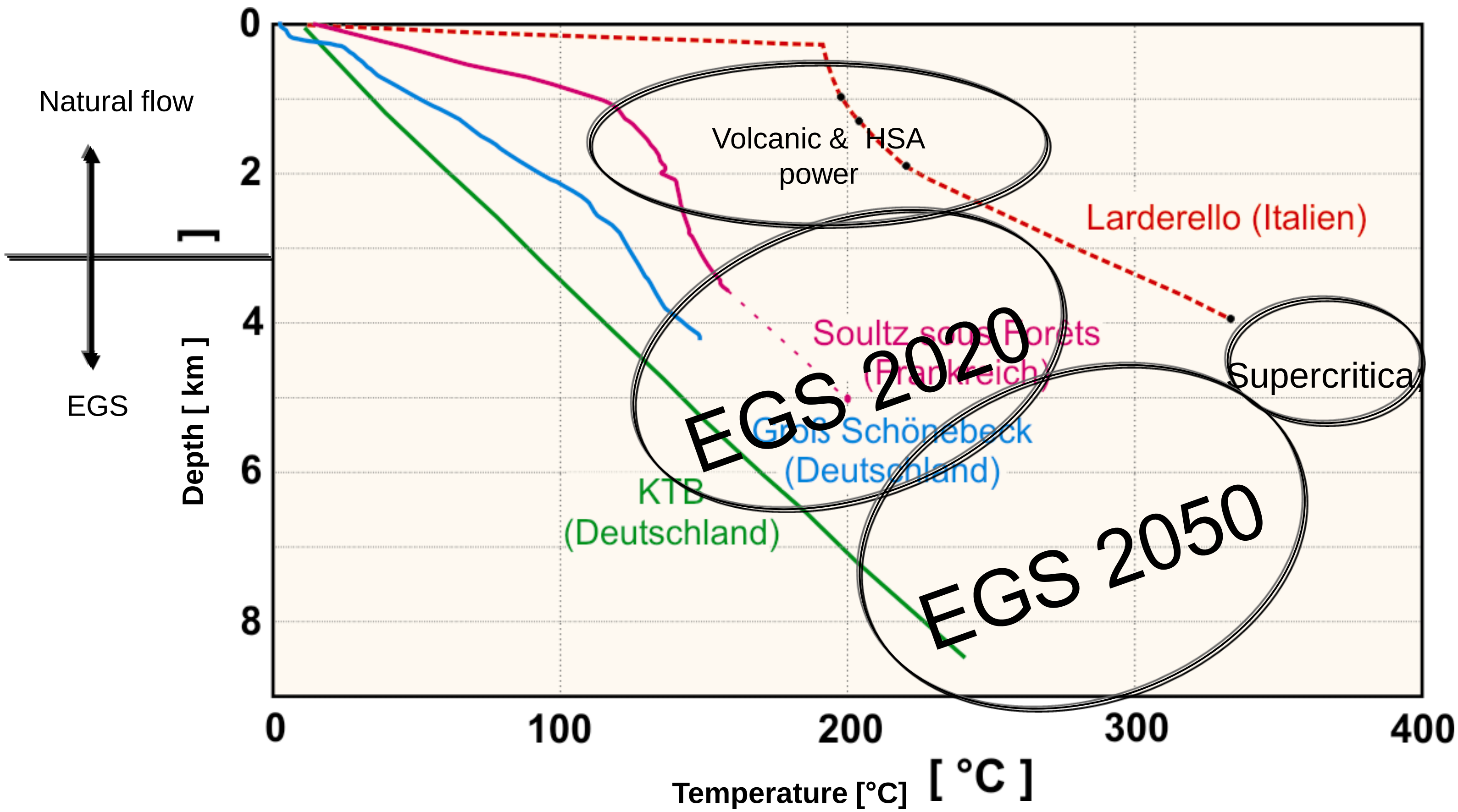


Source:Hot Dry Rock Ltd.

How critical are subsurface conditons

- ***temperature is critical*** → drilling cost is major investement and increases exponentionally with deph → **target high temperature gradient areas**
- **HSA** , **volcanic** (and supercritical) and some **hot rock** rely on occurance of specific geological conditions for **natural fluid pathways** for production (porosity-overpressure, fractures, karst and faults) and chemistry. Probability of natural fluid path ways generally decreases rapidly with depth → **maximum depth is limited**
- **Hot rock/EGS** : fluid path way is enhanced through stimulation → drilling deeper is possible but requires novel drilling and stimulation techniques to increase performance and public acceptability → **maximum depth is not limited**

How do we get the power in different time-lines in different play types



Levels in resource assessment

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

Different protocols on resource assessment and relevance to geoELEC (summary)

- **Regional potential (prospective resources only)**
  - **Level 1** regional assement for (EGS) assesment (IPCC, 2011, Beardsmore et al., 2010, Williams et al., 2008,) Temperature only used as input → theoretical → technical potential
  - **Level 2** Modification of Level 1 based on specific play information
- **Level 2 +3: Ongoing exploration and production for specific leads and prospects and producing fields**
  - Reporting on exploration and production activities
  - Reporting codes well defined for geothermal in Canadian and Australia geothermal reporting coces CanGEA and AGEA

- Uncertainty → State of the art of oil and gas industry on best practices in reporting and assessment of

LEVEL 1- **Theoretical and Technical Potential (1)**

- Expressed as recoverable geothermal energy [MW_e]
  - ➔ „technical potential"
- Assumption: Resource development within 30 years
- Calculation according to Beardsmore et al. (2010) or Willams et al., (2008),concept used in IPCC (2011) and thermoGIS worldedition (2011)
    - Considers heat in place of sediments and crust
      - Beyond threshold depth
      - Cutoff T according to electricity production schemes and
      - Theoretical capacity: $E_{heat\_in\_place} * c_e$
  - Theoretical ➔ technical potential: ultimate recovery factor (UR)
    - Global assessment:
      - Globally: UR ~ 1% of $E_{heat\_in\_place} * c_e$ (IPCC, 2011)
      - Plays, prospects: locally much more than 1% UR → 10-50%,

LEVEL 1 :Theoretical and Technical Potential (2)

Heat Energy in place ➔ Resource Assssessment (Technical Recoverable Potential)

1. Grid geographic region in 5' x 5´ cells	**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**
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.**

after Beardsmore et al. (2010)

Global European Prospective Resource Assessment for Geothermal Power including EGS

- **Level 1** is a **global European assessment** of geothermal electricity potential in Europe at time horizons of 2020 and beyond
- Follows a global assessment strategy at 5‘ x 5‘ nodes
- Does not consider particular play systems
- 1% recovery through conventional power and EGS
- Further assessments (play-oriented):
  - Hot sedimentary aquifers (HSA)
  - Volcanic naturally convective
  - Hot rock

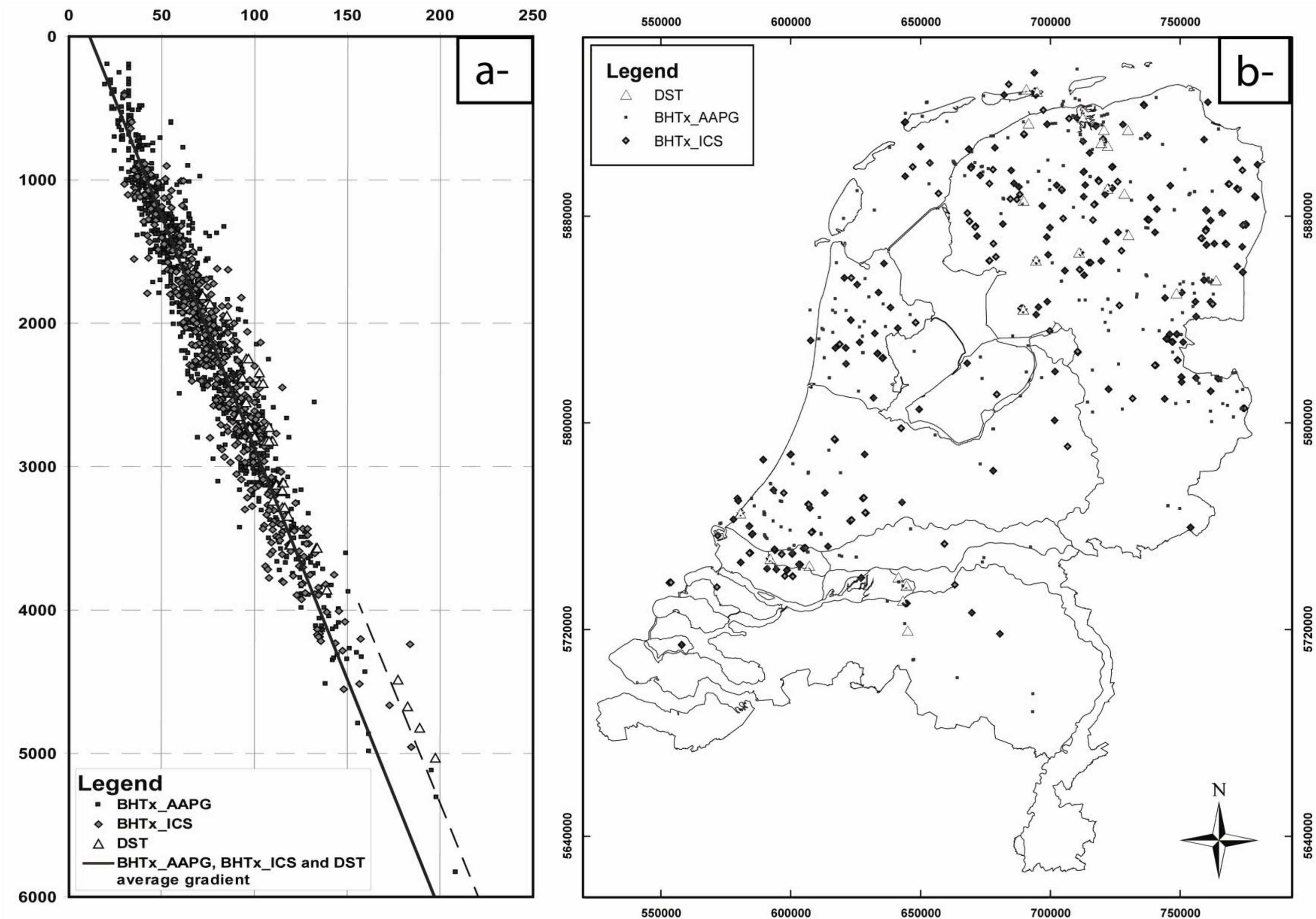
What do we want to deliver in geo_ELEC

- WebGIS with resource potential in map view
  - Theoretical and Technical potential per km2, fr different depth intervals or anticipated time window (e.g. 2020, 2050)
  - Underlying reference data (as maps)
    - Temperature
    - UR map based on spatial variability in Play quality(if feasible) → based on maps of active faults, natural seismicity, volcanoes, thermal springs, HSA, sediment-basement interface, reserved areas etc. I
    - Stress regime
- Data tables to be linked possibly through IGA
  - Ongoing exploration and production activuities. Specific Areas, sites, production and reserves statistics

What do we expect from you in/after this workshop

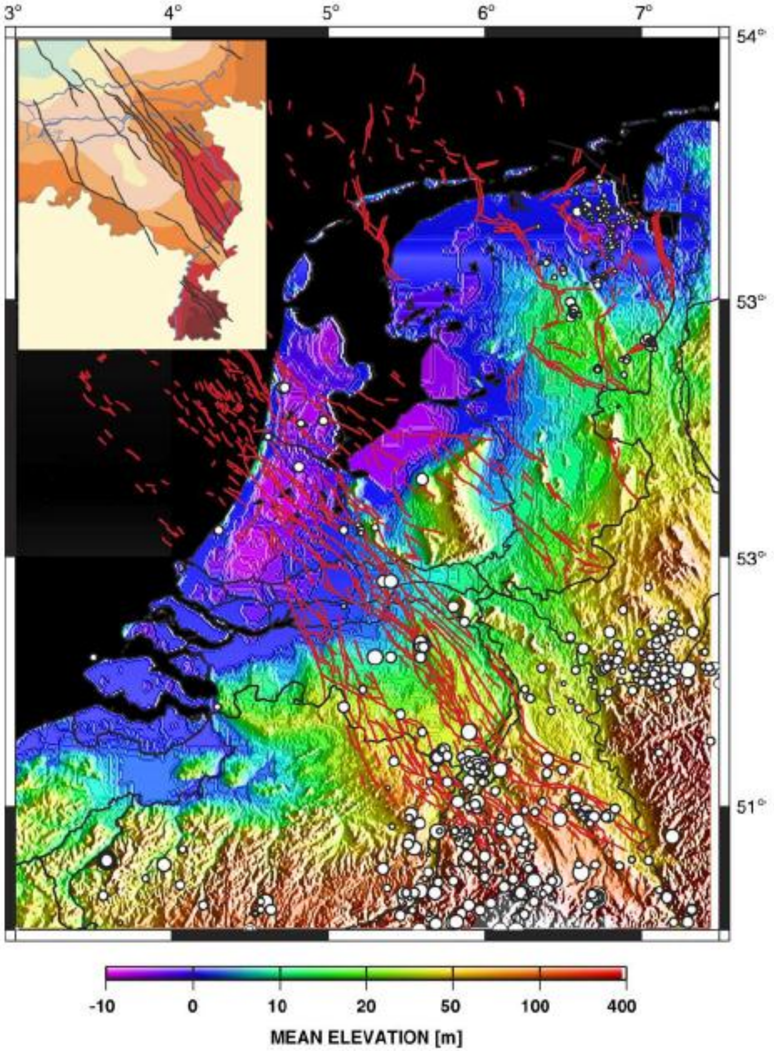
- Access to relevant data global assessment
  - LEVEL 1 EGS → information on **temperature** data. What is publicallt available to compile in terms of heat flow, BHT data. Do you have models of deep sediment and upper crustal temperature. If not can you provide relevant sediment (e.g. thickness) and basement data which can be used to derive a model.
  - LEVEL 2 → different plays: do you have supporting data and models relevant to assessment of specific plays (e.g. HSA, volcanic), increasing local recoverablity of theoretical potential or locally modifing conditions not captured in regionalised models.
  - information on Specific plays, prospects, leads to be colleced in a database (what is your country reporting procedure)
  - **FILLING IN QUESTIONAIRE**

Example from the Netherlands: temperature data



Bonte et al., submitted

Example from the Netherlands: active faults and seismicity

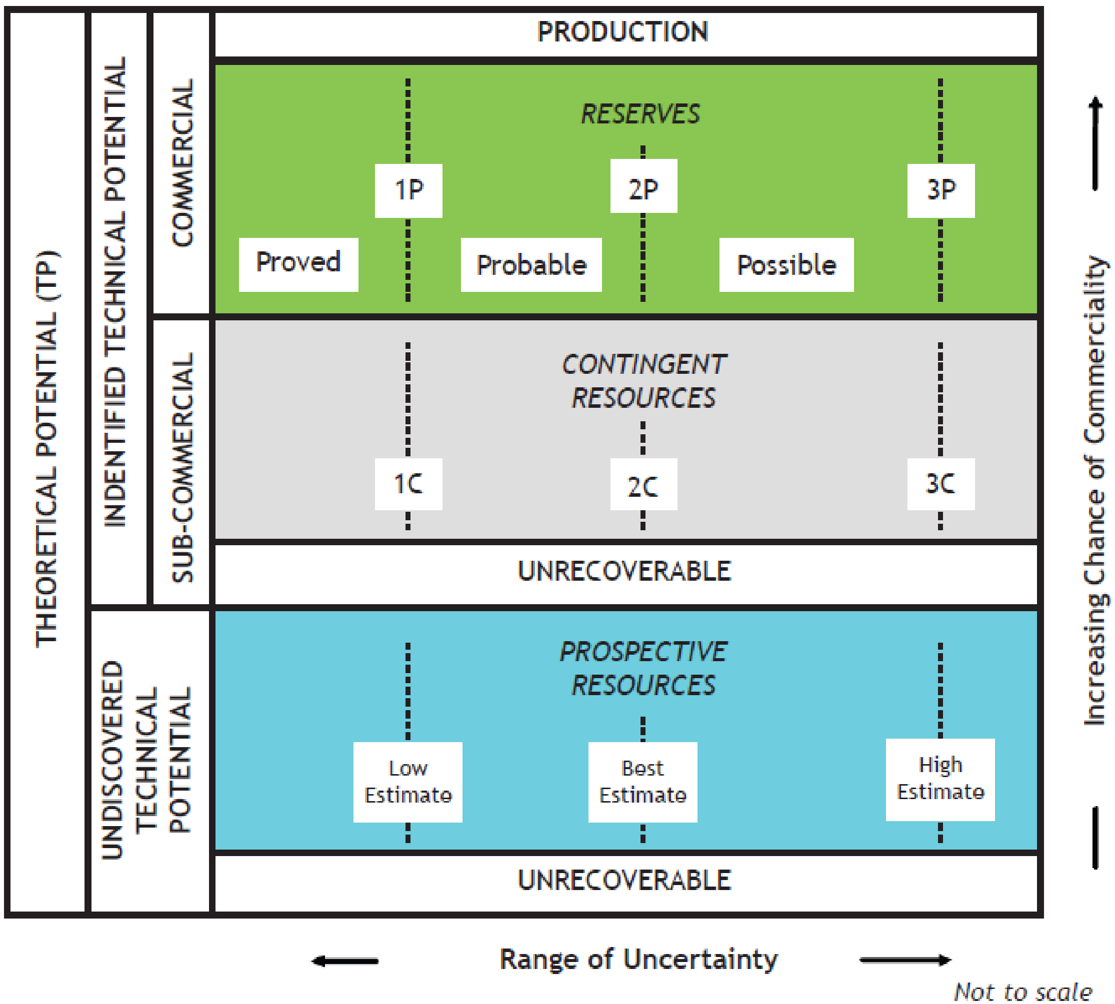


Cloetingh et al., 2010

Reference data to use/include:

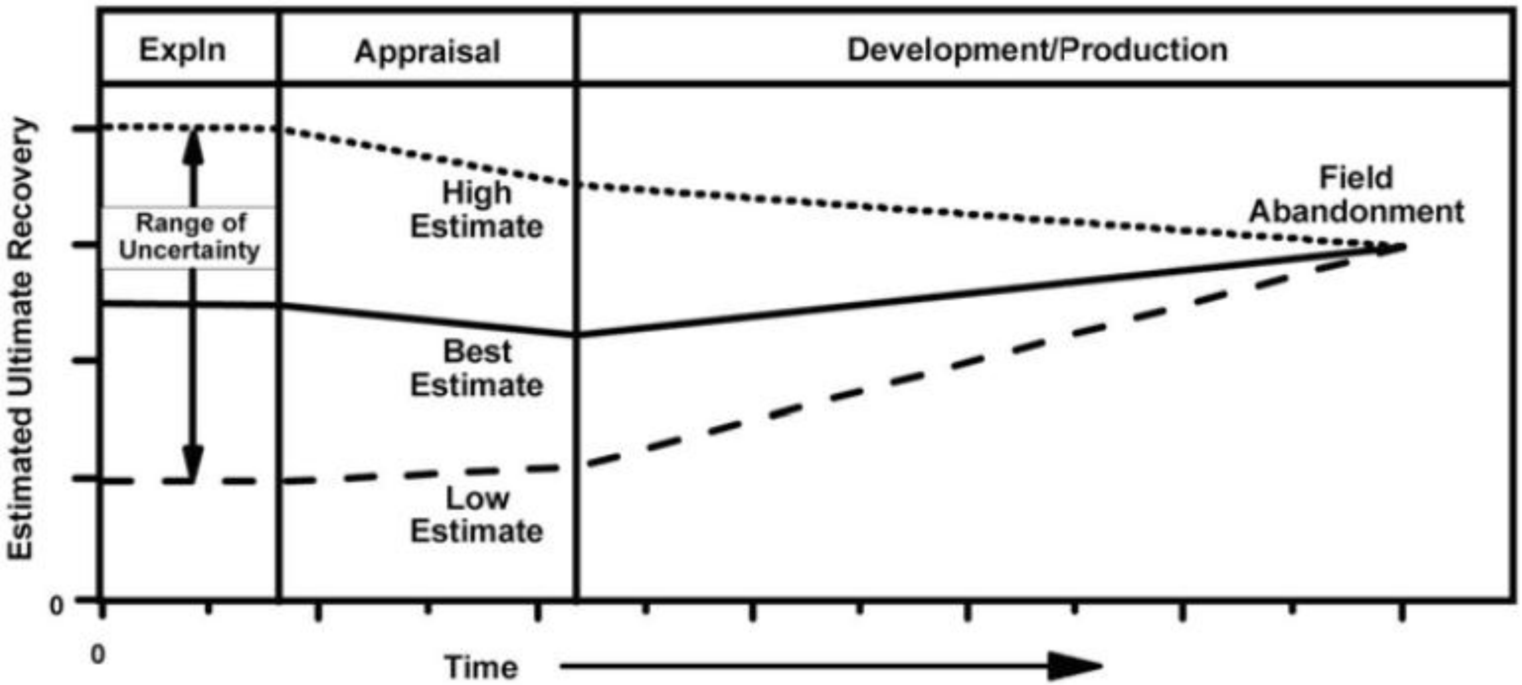
- Updated heat flow map
- Geothermal atlas
- Volcanoes
- Sediment-basement map of europe (which is best, can you contribute?)
- Primary probability trends with depth
- Probability for secondary permeability (e.g. Bavaria)
- Active faults overview
- Natural seismicity/PGA
- 3D strength/ temperature (through VU Amsterdam)

Reserve/Resource Categorisation Terminology (2)

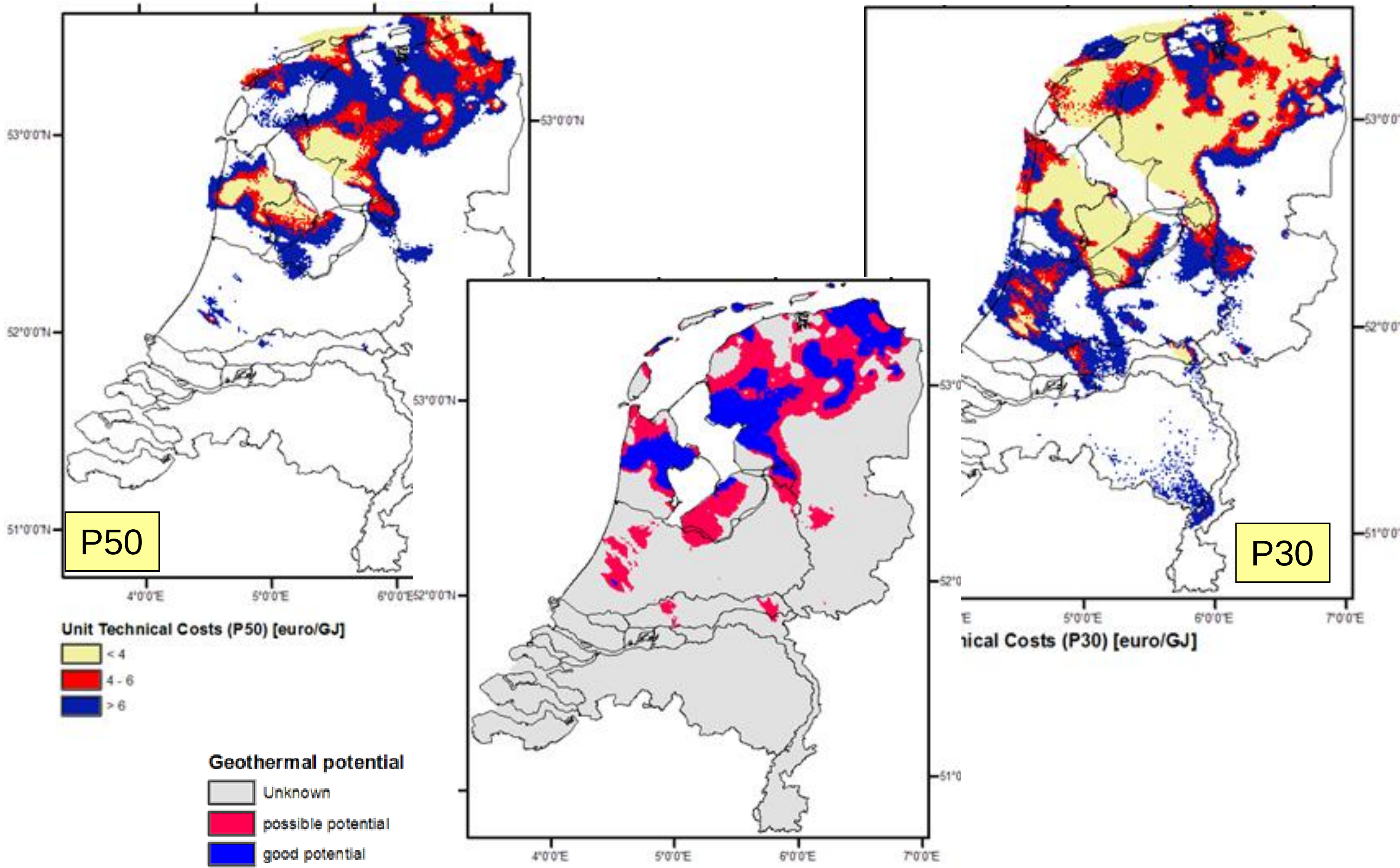


Funneling Uncertainty During Project Lifetime

- Cumulative scenarios
- Declining uncertainties with increasing lifetime



Potential Map for an aquifer in Netherlands



Existing Reporting Code for Geothermal Projects

- **Australian Geothermal Reporting Code (AGEA-AGEC, 2010) and lexicon**
- **Canadian Geothermal Reporting Code (CANGEA, 2010)**

A '**Geothermal Resource**' is a Geothermal Play which exists in such a form, quality and quantity that there are **reasonable prospects for eventual economic extraction. If there is no reasonable prospect for eventual economic extraction then the energy in question should not be included in estimates of Geothermal Resources**. The location, quantity, temperature, geological characteristics and extent of a Geothermal Resource are known, estimated or interpreted from specific geological evidence and knowledge. Geothermal Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories.

Existing Reporting Code for Geothermal Projects

- **Australian Geothermal Reporting Code (AGEA-AGEC, 2010)**
- **Canadian Geothermal Reporting Code (CANGEA, 2010)**
- Applicable for particular locations
- Not suitable for global assessments
- Aimed at transparency for investors
- Generic worldwide for two geothermal plays:
  - D1: naturally convective 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)

Limited Applicability of the AGEA/CanGEA Codes in GEO-ELEC

- Not directly to be used for global assessment

- Appropriate for any country in Europe for resource reporting
  - For reporting specific exploration outcomes
  - Results on resources and reserves, if available

Australian Code: Format Definition

	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.

AGEA-AGEC (2010)

Thank you for your attention!