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and Earth Resources,
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ADELE MANZELLA

GEOTHERMAL POTENTIAL:

From Italy to Europe, perspective and case studies

E.ON Energy Research Center
RWTH AACHEN UNIVERSITY

Geothermal Potential between Italy and Europe

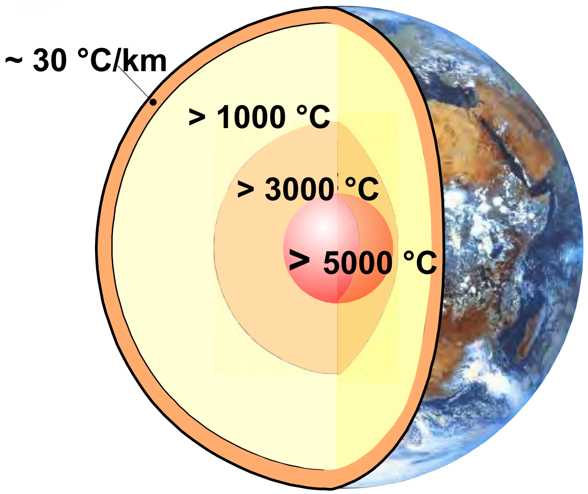
1. Why Geothermal
2. Energy needs in Italy
3. Our Projects and their targets

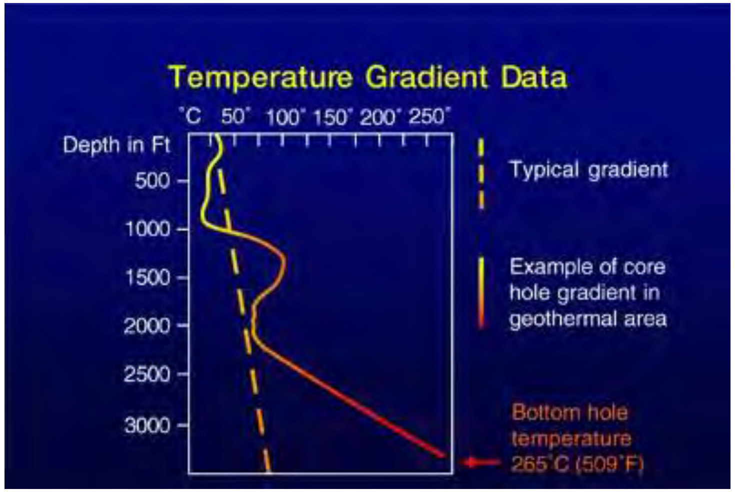
Perspectives and case studies

What are the benefits of geothermal? Have we done all we can?

Why Geothermal Energy

WHY GEOTHERMAL ENERGY





The basis of geothermal energy is the immense heat content of the earth's interior: the Earth is slowly cooling down. Since billions of years the heat in the Earth Crust is constantly supplied by the decay of natural radioactive isotopes or the cooling of hot, shallow magmatic bodies.

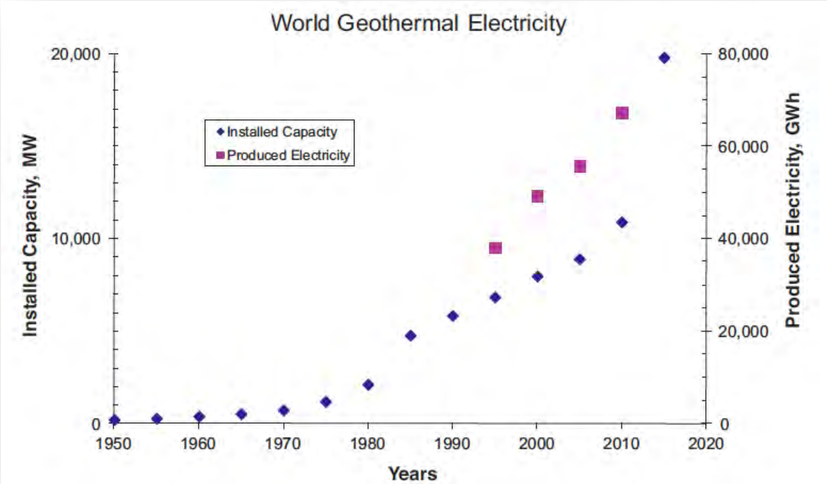
The resource is vast and ubiquitous and has a corresponding **large potential for utilization**.

WHY GEOTHERMAL ENERGY

Depth		
0 - 500 m	Dry/hydrothermal Shallow Reservoir	Mostly for Direct uses of heat Borehole Heat Exchanger
500 – 5000 m	Hydrothermal Systems: shallow and deep reservoir	Power generation – Heat&Power generation Conventional technologies – EGS (Engineered Geothermal Systems)
More than 5000 m	Hot deep dry/wet rock reservoir	EGS – Supercritical fluids Future perspectives

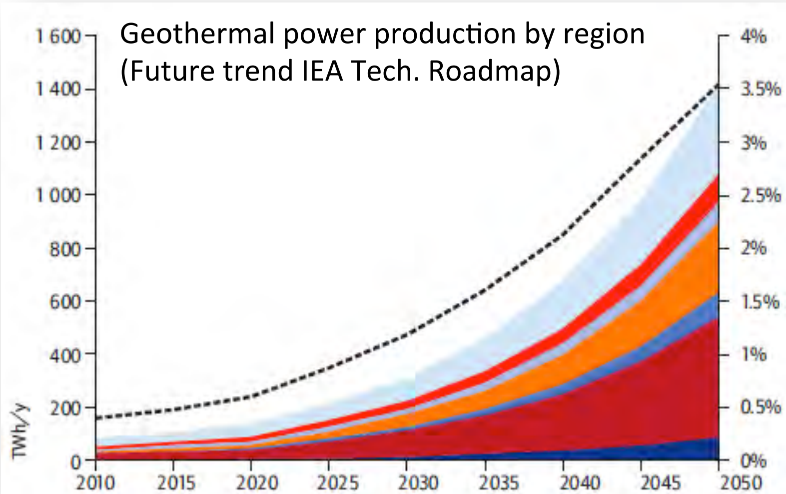
Depending on the depth and the physical properties of the resource, the heat&power production, the upfront cost and the appropriate utilization technology may vary.

WHY GEOTHERMAL ENERGY



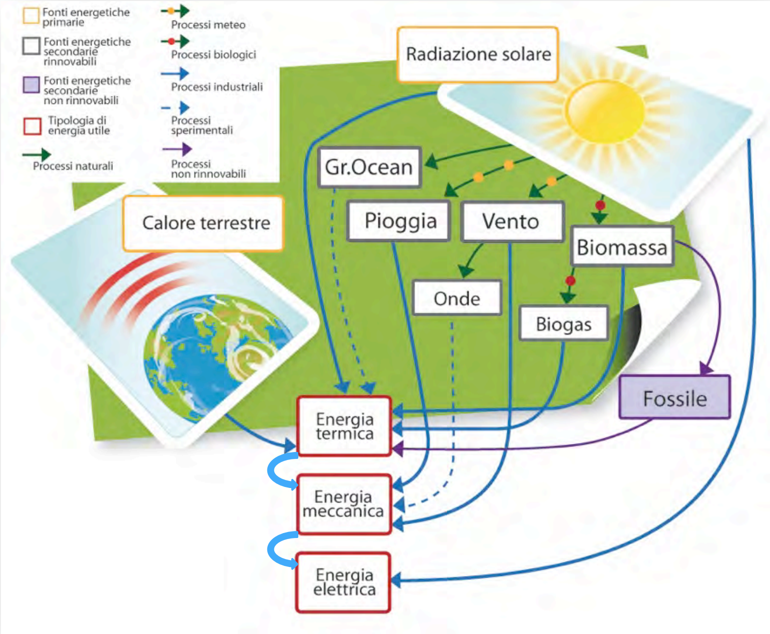
Bertani, 2012

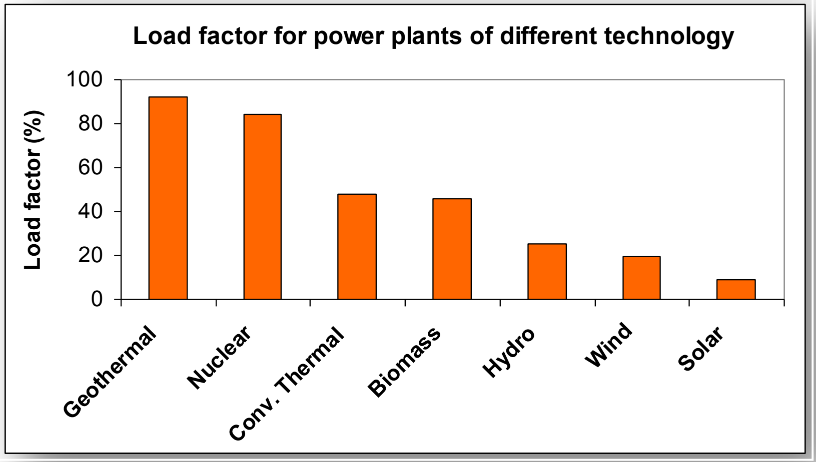
The two main applications of geothermal energy, electric power generation and direct use of heat, are currently producing more than 60 TWh_e with 10 GW_e of installed capacity, and about 300 TJ/yr with 30 GW_{th}



And are **constantly growing**.

WHY GEOTHERMAL ENERGY

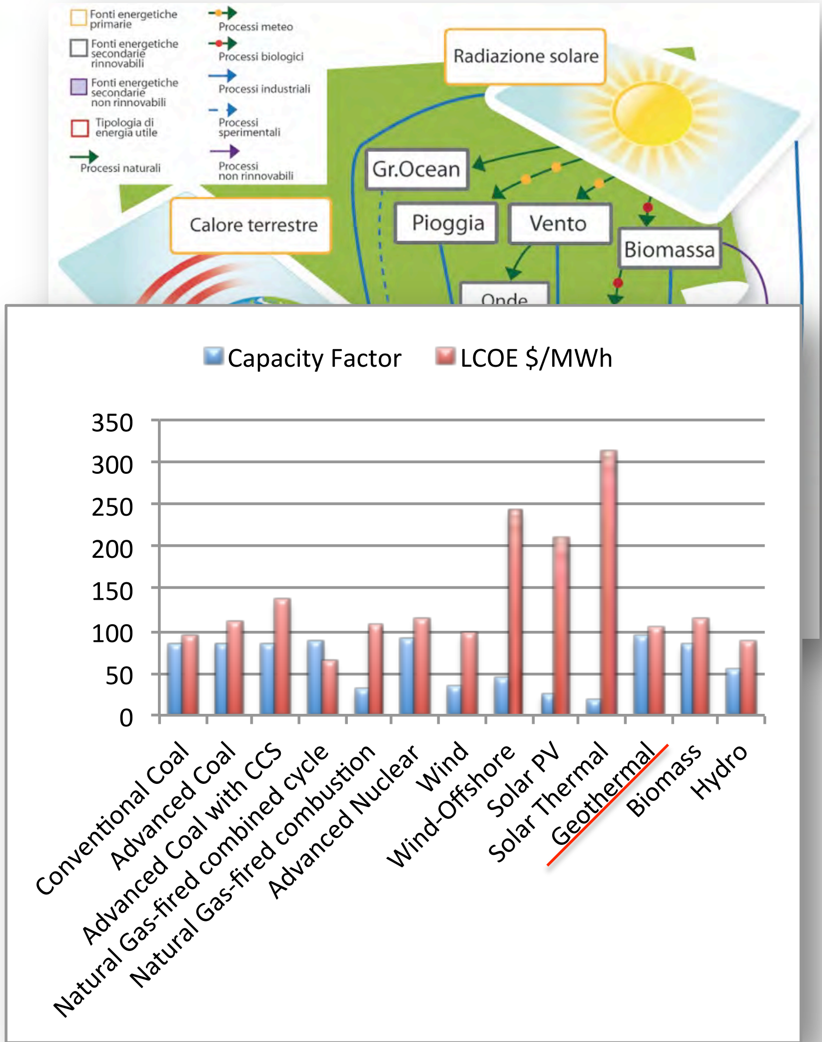




Not depending, directly or undirectly, on sun, geothermal may produce 24 hours per day:

a **base-load energy** like fossil and nuclear sources

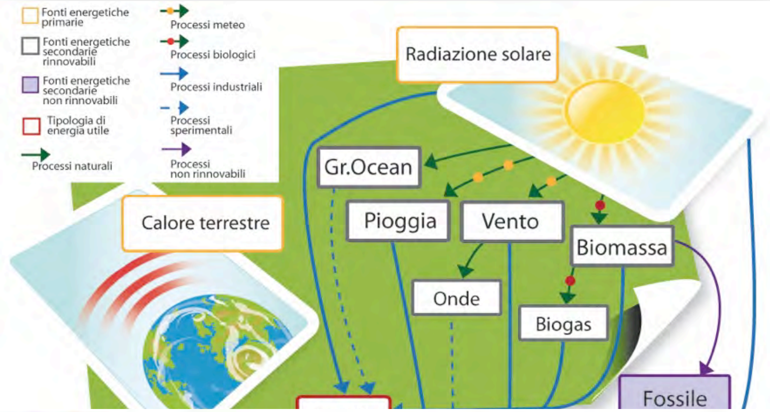
WHY GEOTHERMAL ENERGY



Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011, EIA

The **total cost (LCOE)** of geothermal power production is **cheap** if compared to those of others renewables, but the capital, **up-front costs** remain **high**, due to the scarcity of on-site data, the difficulty to forecast the production prior to drill combined with the high drilling costs.

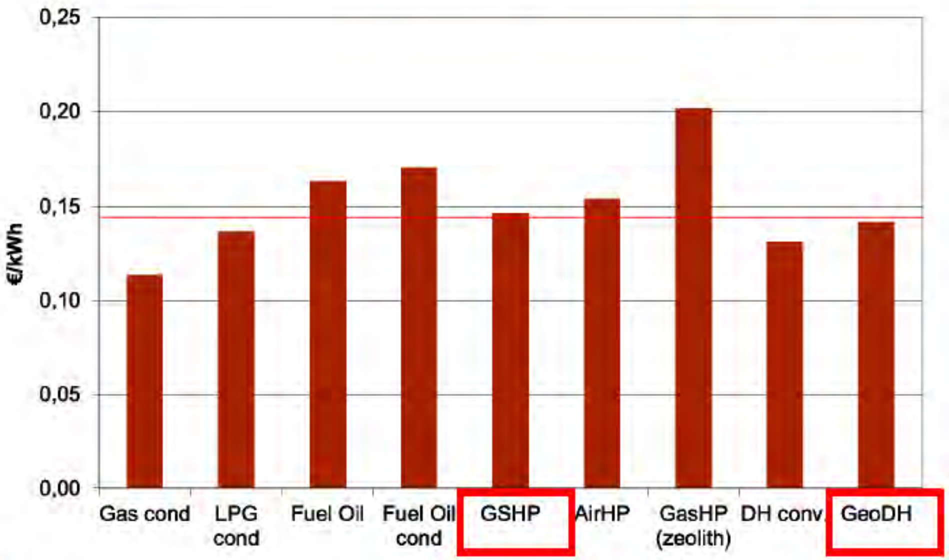
WHY GEOTHERMAL ENERGY



The **total cost** of geothermal heat production is **cheap** if compared to those of others sources. Many countries are scarcely aware.

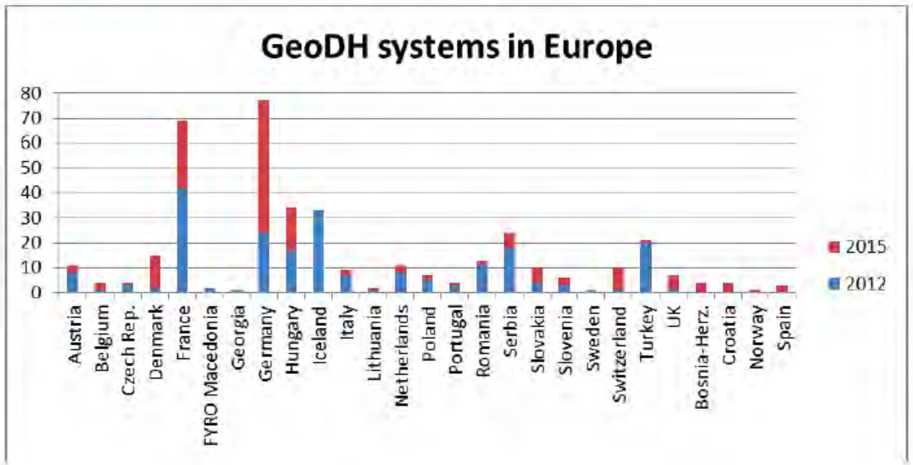
EGEC GEOTHERMAL

Full cost of Heat, calculated for small building or flat



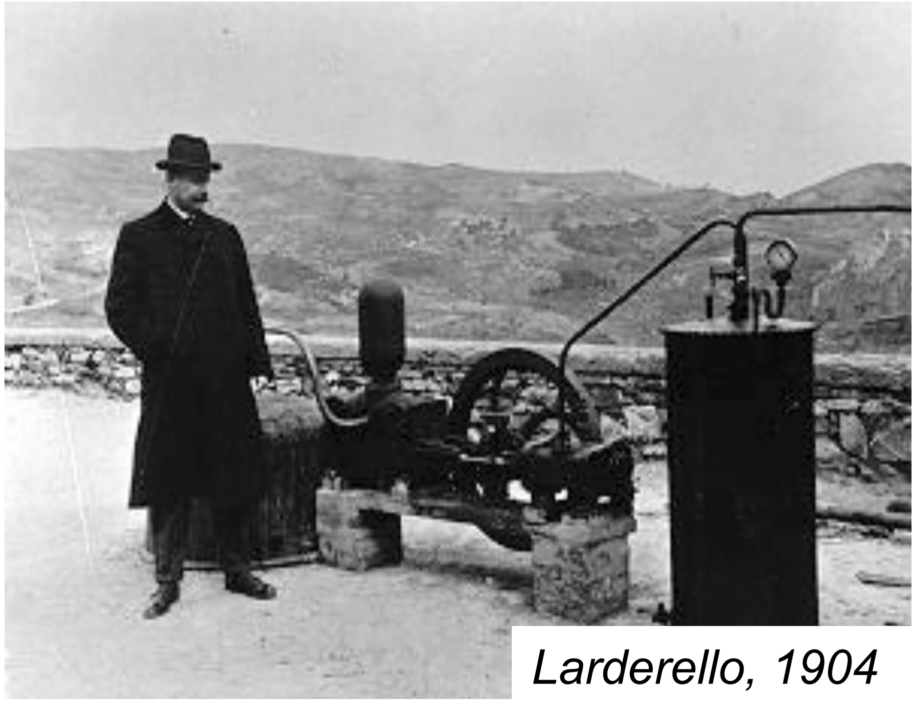
EGEC GEOTHERMAL

GeoDH Systems in Europe



Why geothermal energy

The real **geothermal potential is scarcely known**, it is seldom defined in detail by the countries and properly introduced in the Energy Plans



Larderello, 1904

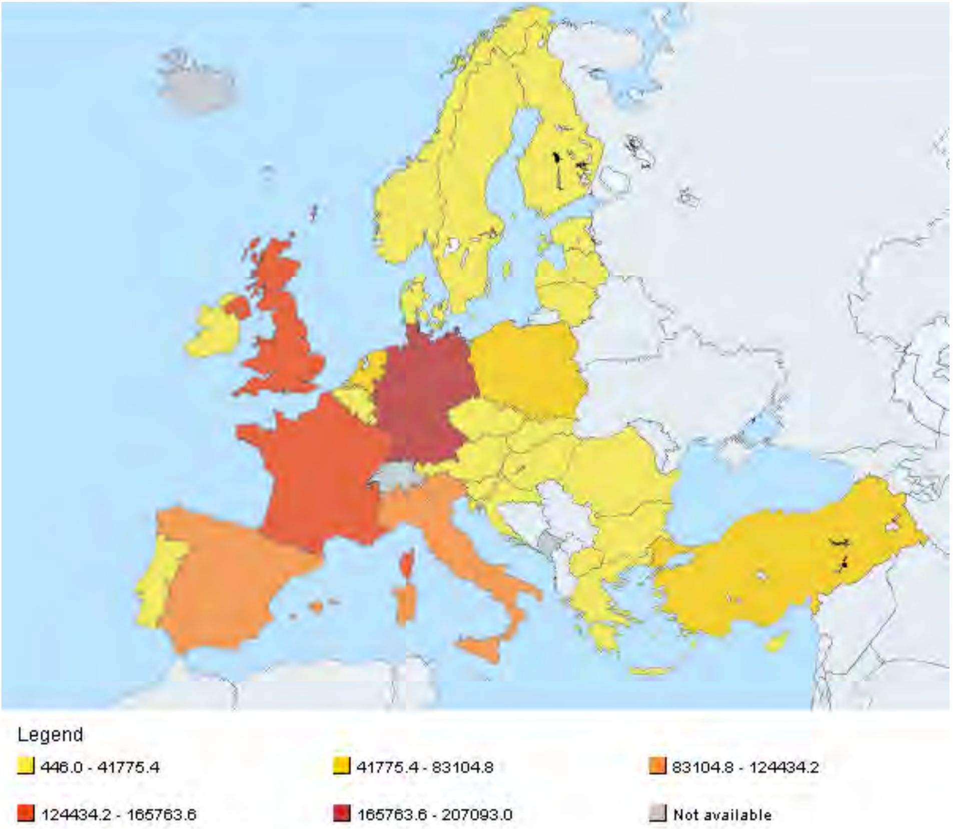
Although geothermal energy has a long tradition for application in Italy, there is little **awareness** of its potential, and the role it might play for energy production among renewables.

2

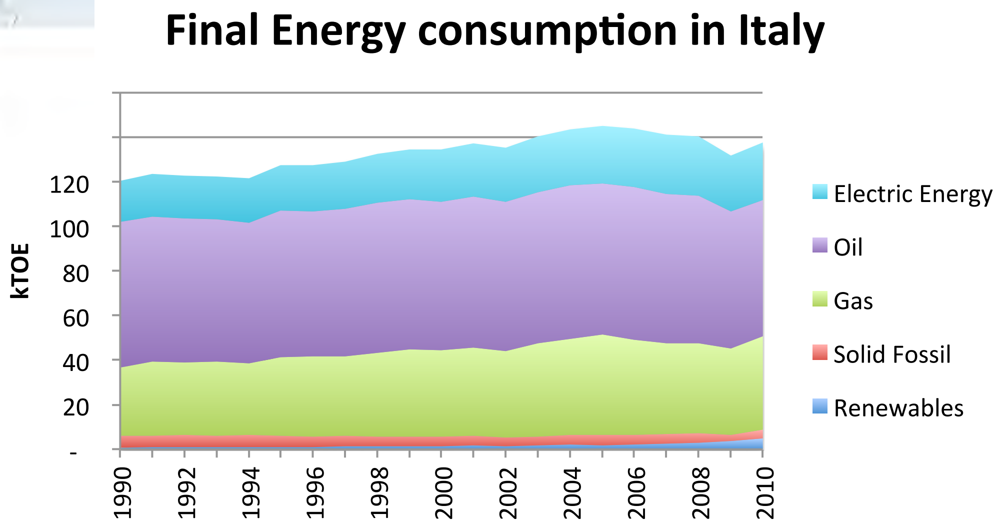
What is required for the expansion of geothermal energy application, to increase the number of projects as well as the variety of uses

Energy needs in Italy

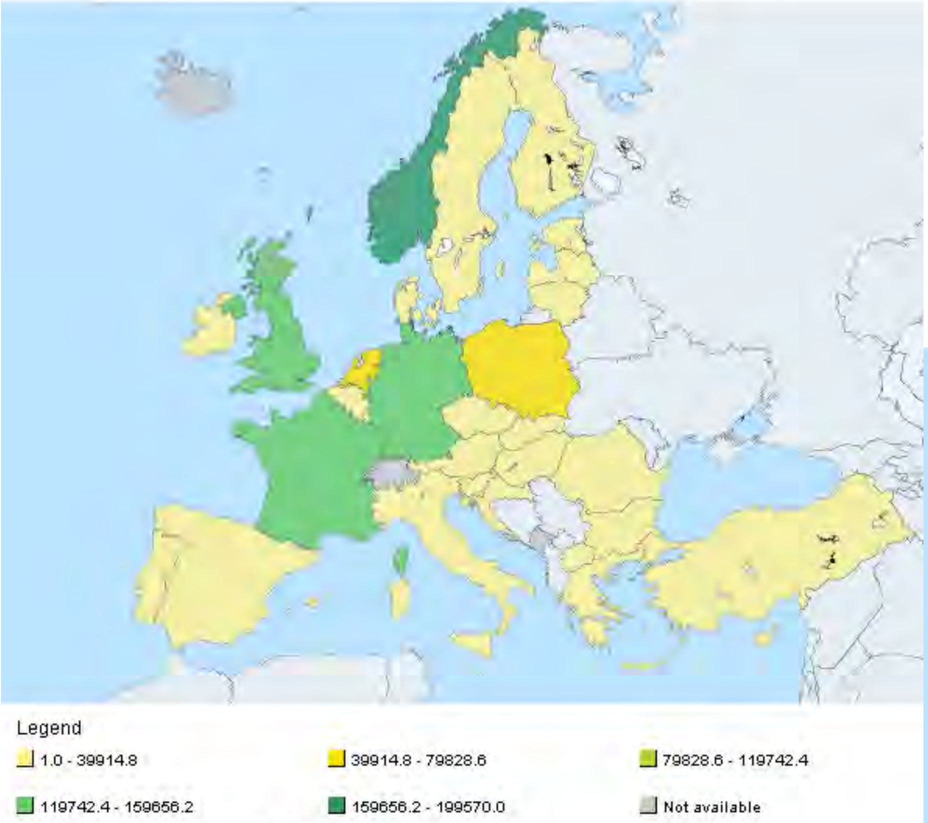
ENERGY NEEDS GEOTHERMAL ENERGY



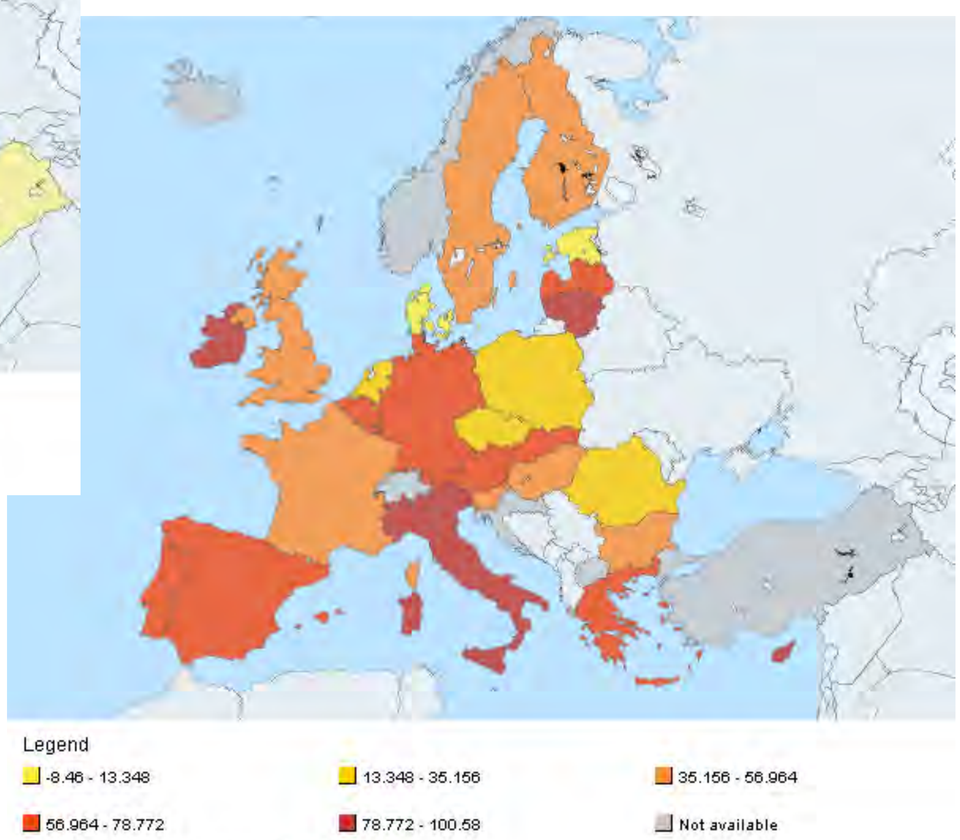
Final energy consumption
(kTOE), Eurostat
Italy 2011: 123 MTOE



ENERGY NEEDS GEOTHERMAL ENERGY

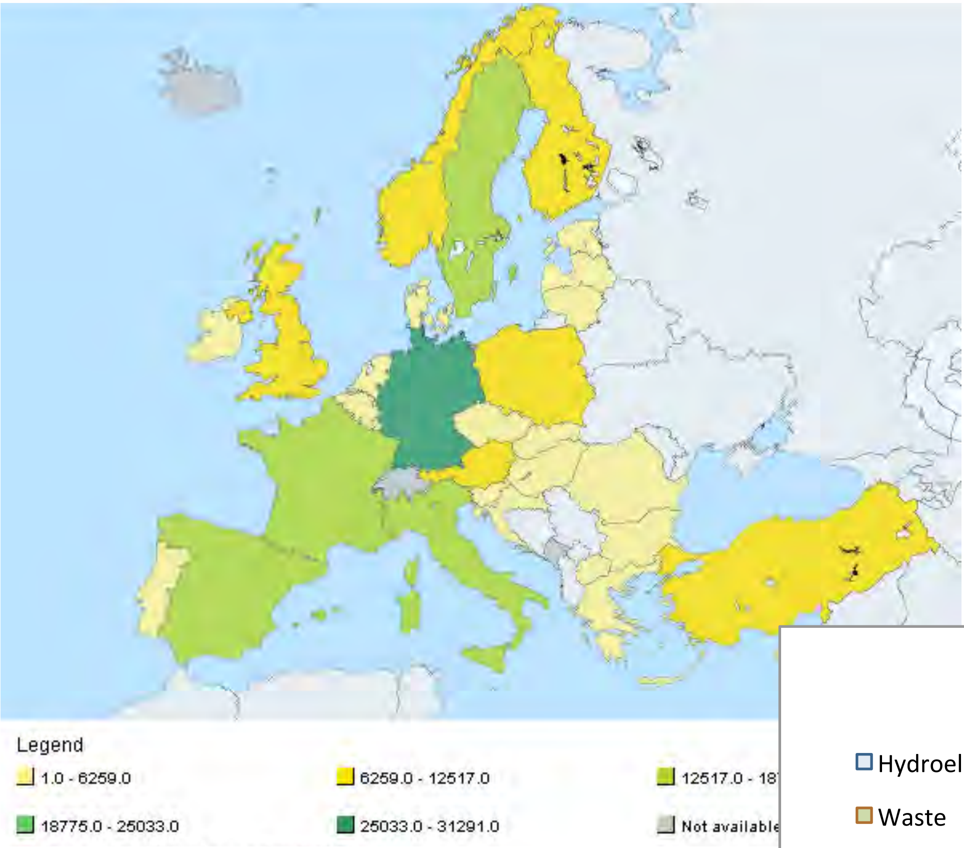


Total production of primary energy (kTOE), Eurostat
Italy 2011: 32 MTOE

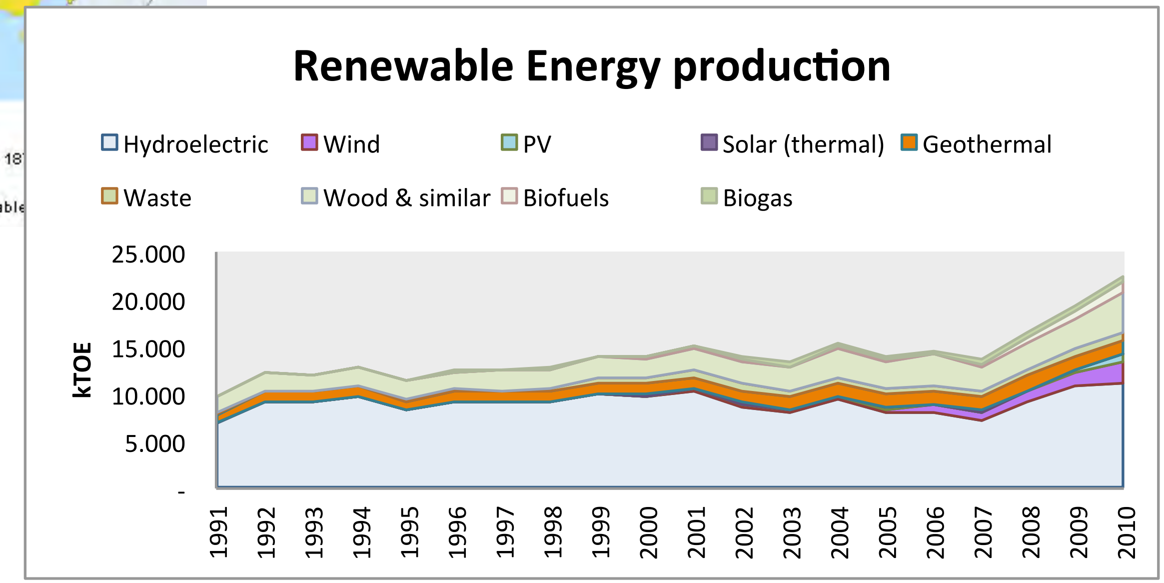


Energy dependence (%), Eurostat
Italy 2011: 81.3%

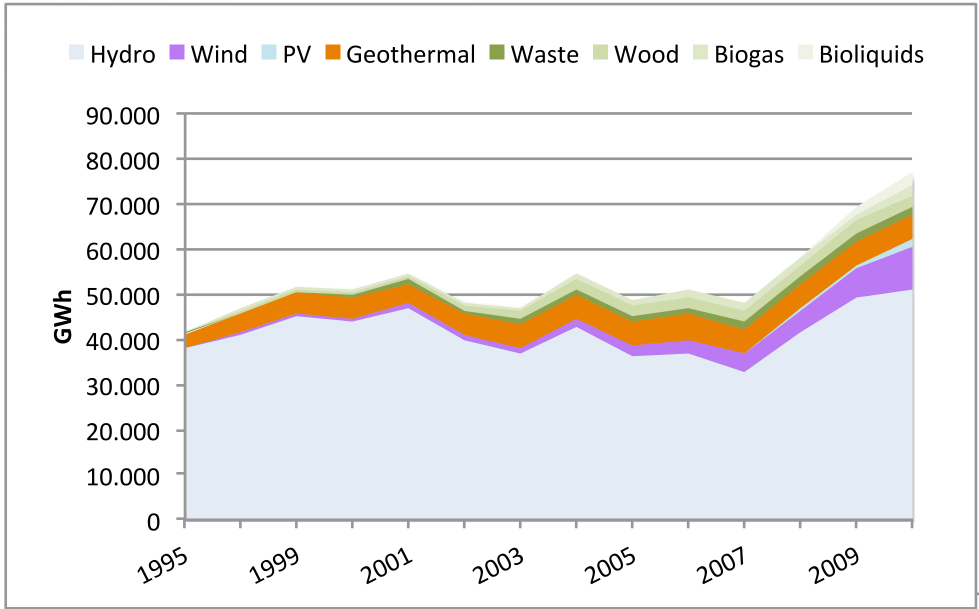
ENERGY NEEDS GEOTHERMAL ENERGY



Primary production of renewable energies (kTOE), Eurostat
Italy 2011: 18 MTOE

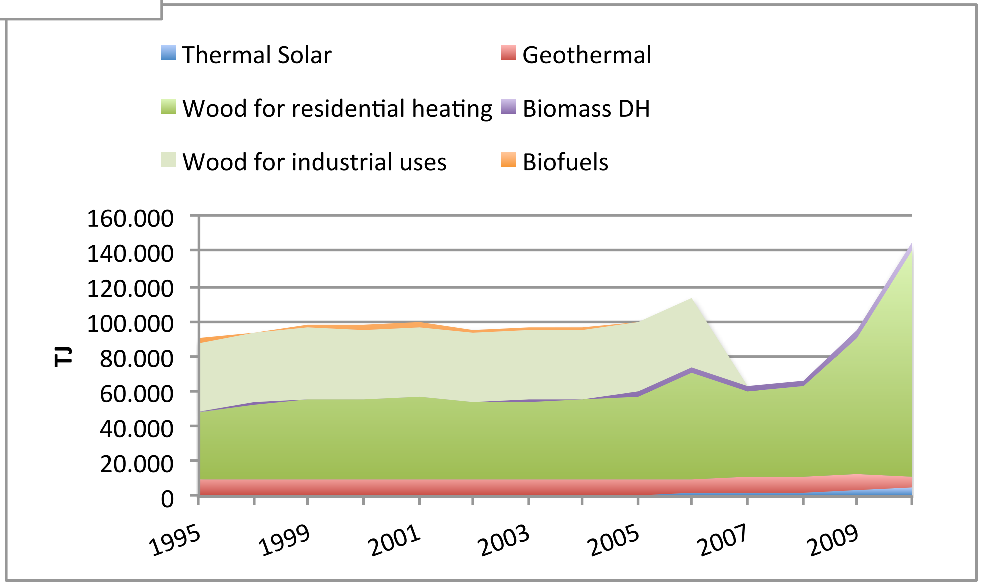


ENERGY NEEDS GEOTHERMAL ENERGY



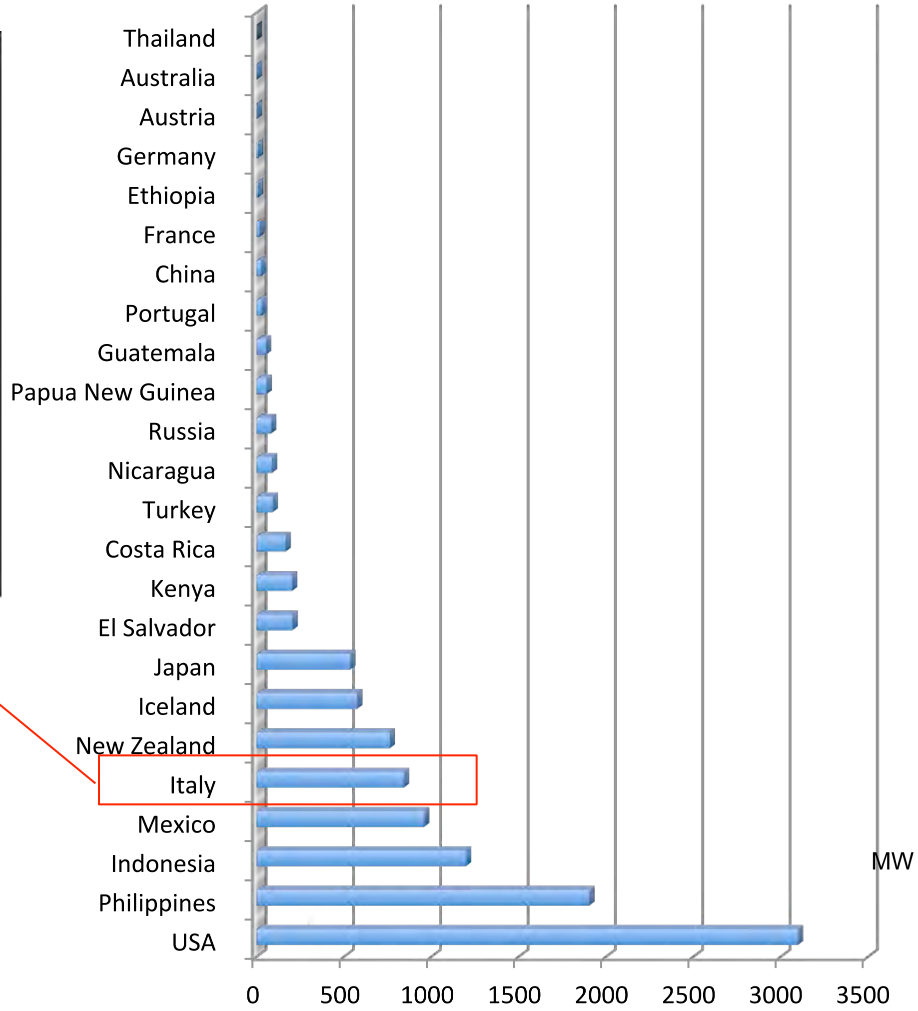
Power production from renewable energies in Italy

Heat production from renewable energies in Italy



ENERGY NEEDS GEOTHERMAL ENERGY

Italy is a geothermal country



Geothermal power production:

8,5 % world's power production,
1,9 % national power need
25 % Tuscany power need

ENERGY NEEDS GEOTHERMAL ENERGY

Larderello and Travale/Radicondoli are two parts of the same field, covering a huge area of approximately 400 km^2, producing super-heated steam at a pressure of 2 MPa and temperature in the range 150–270 °C. At Larderello, the exploited area is 250 km^2, with 22 units for a total of 594 MW installed capacity; the Travale/Radicondoli, covers a surface of 50 km^2, and the installed capacity is 160 MW (6 units). The most explopited are now the deep reservoirs, with pressure of 6–7 MPa and temperature of 300–350 °C, at depth of 3000–4000 m

Mount Amiata area includes two water dominated geothermal fields: Piancastagnaio and Bagnore. In both the fields a deep water dominated resource has been discovered under the shallow one, with a pressure of 20 MPa and a temperature around 300 °C.

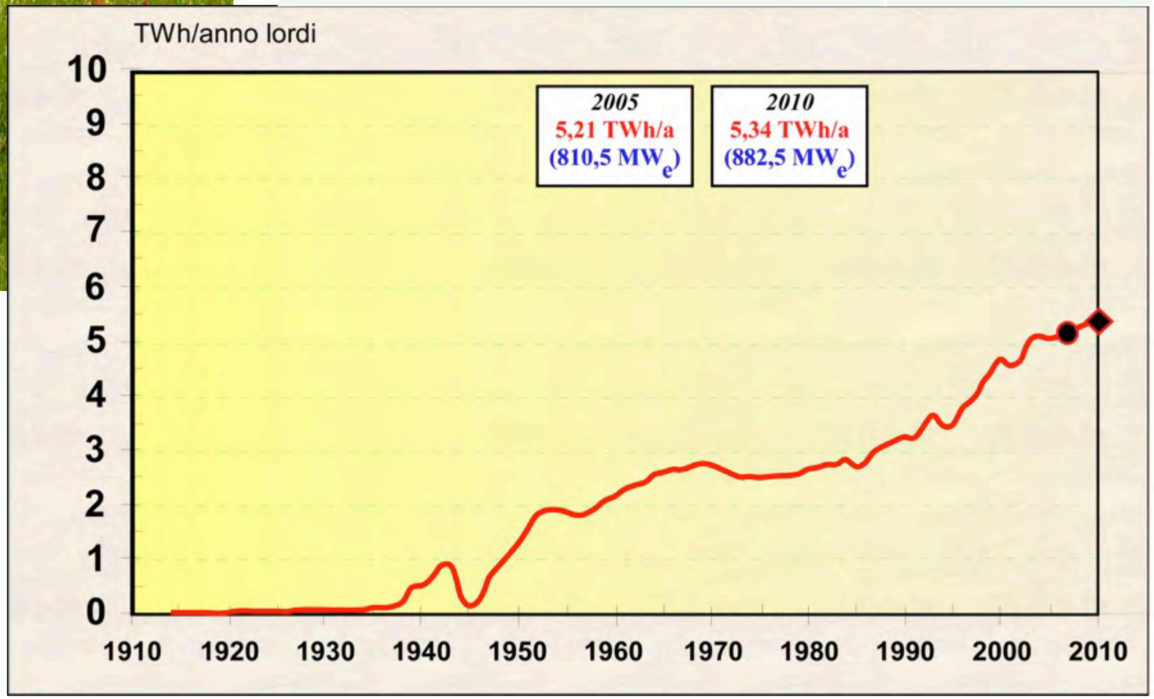
Presently, there are 5 units with 88 MW of installed capacity: one in Bagnore and four in Piancastagnaio.

Projects for a further 112 MW have been approved and will be developed in the coming years: new plants in Larderello/Travale, Bagnore and Piancastagnaio, with a net increase of 80 MW (including the decommissioning of some older units).

From Bertani, 2011

ENERGY NEEDS GEOTHERMAL ENERGY

Gross capacity	882 MW
Power production	5400 GWh/y
Units	35
Wells in operation	308
Reinjection wells	69
Steam network	207 km
Reinection water network	298 km

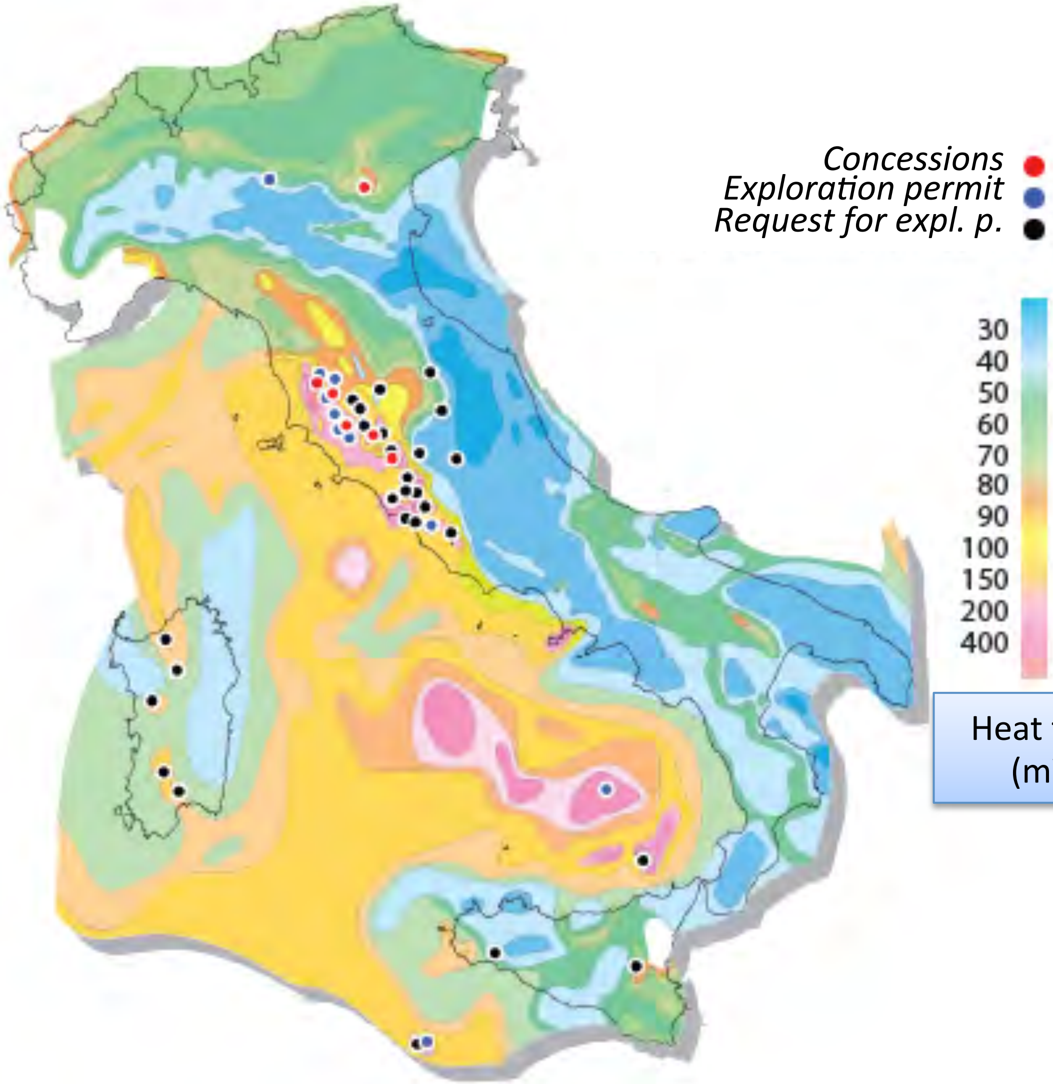


ENERGY NEEDS GEOTHERMAL ENERGY

There is a growing interest for geothermal, testified by the high number of requests for exploration projects.

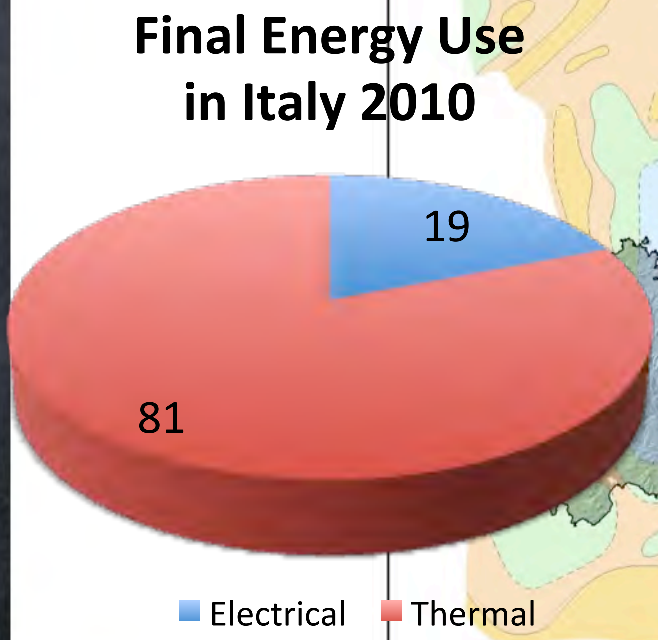
Most of them are located in the high heat flow areas where hydrothermal systems are expected.

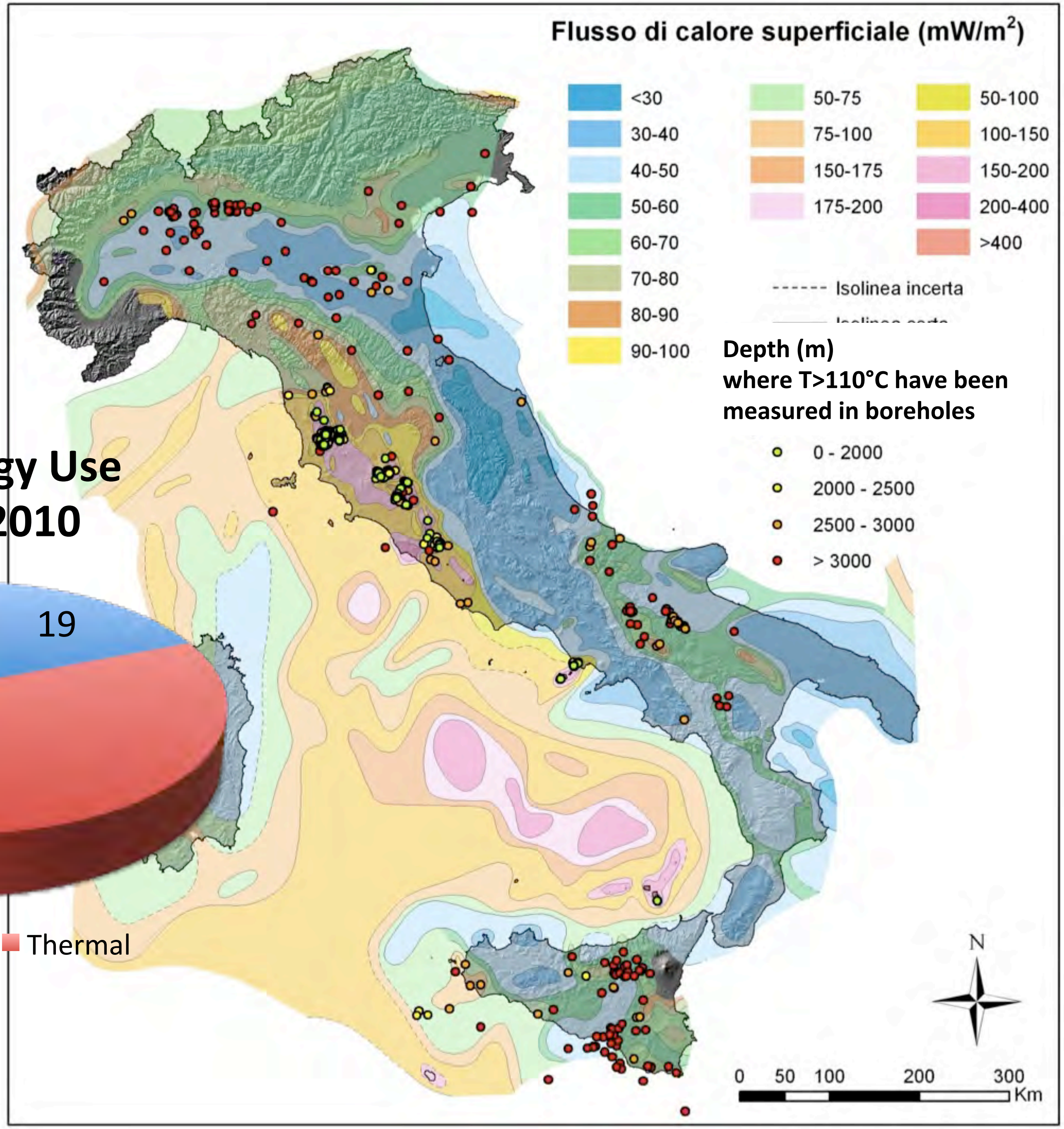
We should not stop there.



Heat flow map (mW/m^2)

Opportunities





REQUIREMENTS

A comprehensive identification of resources and opportunities, as well as an accessible collection of data and information

A clear and easy to follow regulation for authorizations in the exploration, drilling and exploitation phases of the project

The promotion and dissemination of technology, values, economics

Research and technological development

Actual projects and actions

Projects and efforts

PROJECTS AND EFFORTS

VIGOR
ENERGIA DALLA TERRA

Evaluation of Geothermal Potential for the *Regioni Convergenza*

An Agreement between the Ministry for Economic Development and CNR, funded in the frame of POI for RES, targeting at development of geothermal demonstration projects (power production and direct uses)

GEOTHERMAL ASSESSMENT

Before VIGOR

Inventory of National Geothermal Resources

By CNR, ENEA, ENEL e ENI

Law No 896 of **1986**.

It resulted in maps and reports.

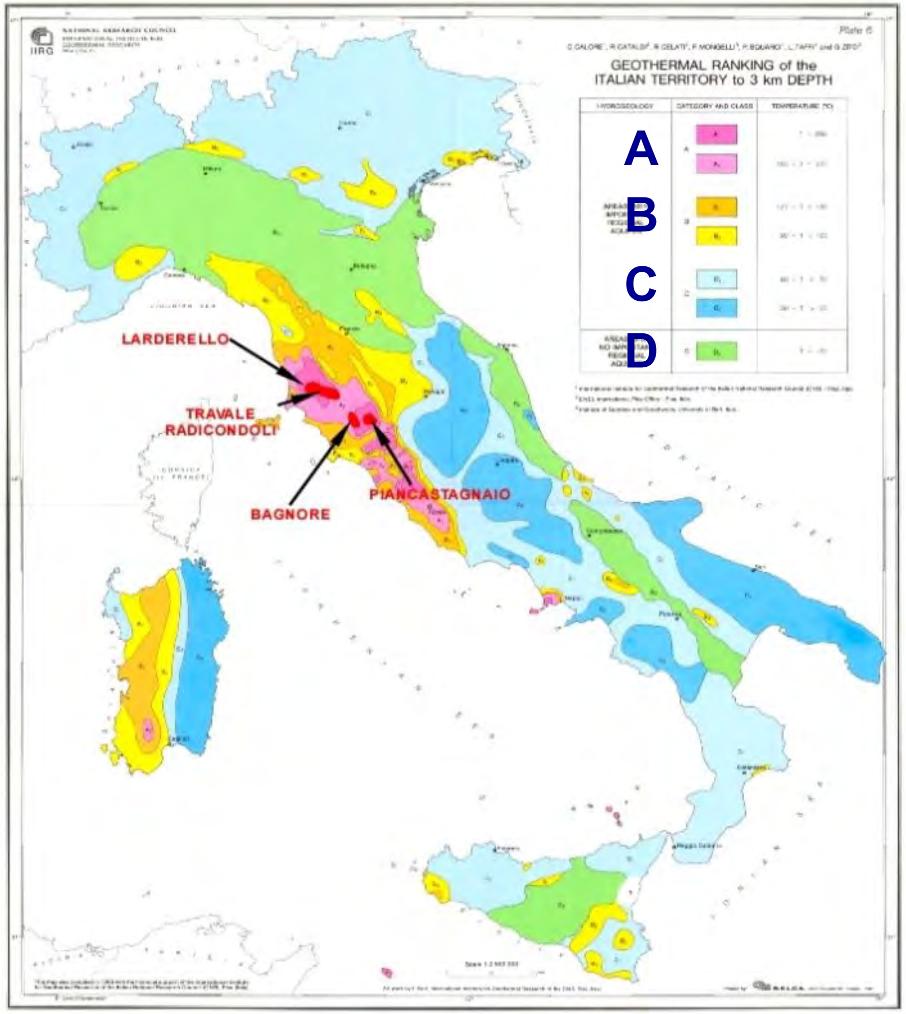
The Geothermal Ranking was based on temperature and fluid availability

A: areas where at least one aquifer, at depth **< 3 km**, has temperature **> 150**°C

B: areas where at least one aquifer, at depth **< 3 km**, has temperature in the range **150 – 90** °C

C: areas where at least one aquifer, at depth **< 3 km**, has temperature in the range **90 – 30** °C

D: areas with only minor aquifers at depth **< 3 km**, temperature **< 150**°C



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WHAT AND WHERE

Lavorazione foraggio

Cartiere

WHAT AND WHERE

Activities	Where
Data collection and organization	In the 4 Regions
Evaluation of shallow resources	Regional Area 1: Calabria Area 2: Campania Area 3: Puglia Area 4: Sicilia Area 5: Puglia
Evaluation of deep resources	Regional Area 6: Campania Area 7: Sicilia Area 8: Calabria
Evaluation of geothermal potential	Regional and in the 8 areas
Dissemination	In the 4 Regions

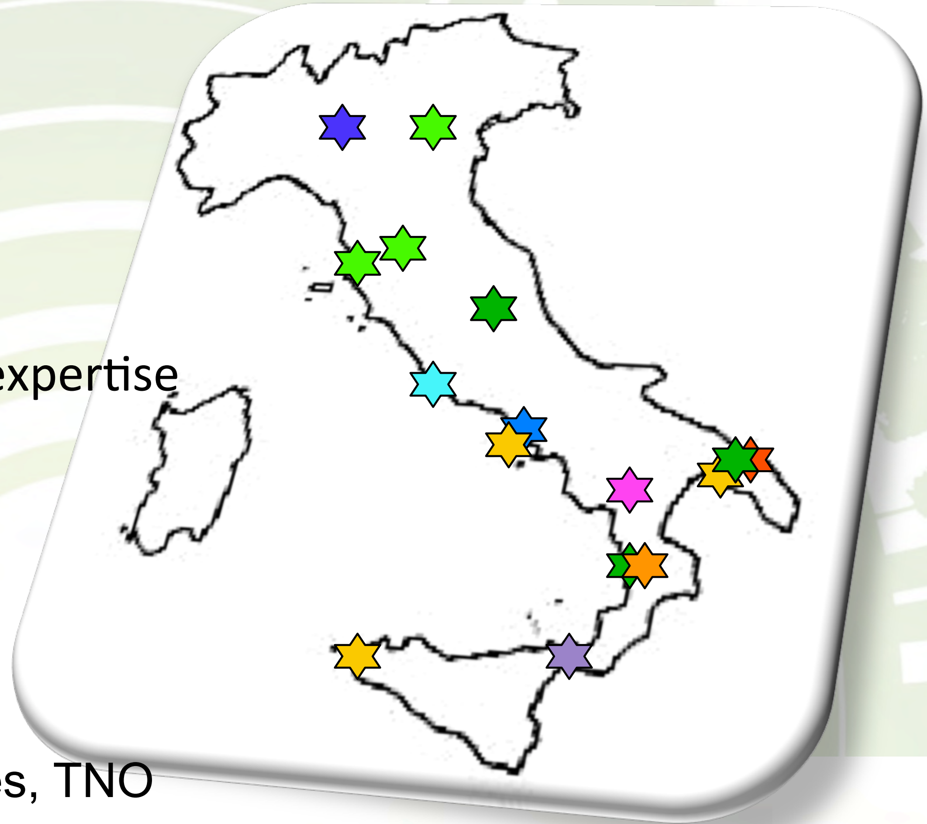
TEAM

6 Institutes workig in the 4 regions

- IAMC
- IREA
- IRSA
- IRPI
- ITAE
- IPCF

and 4 in other regions, providing expertise and technical support

- **IGG** – scientific coordination
- **IDPA**
- **IMAA**
- **IGAG**



+ collaborations with INGV, Universities, TNO RWTH-Aachen

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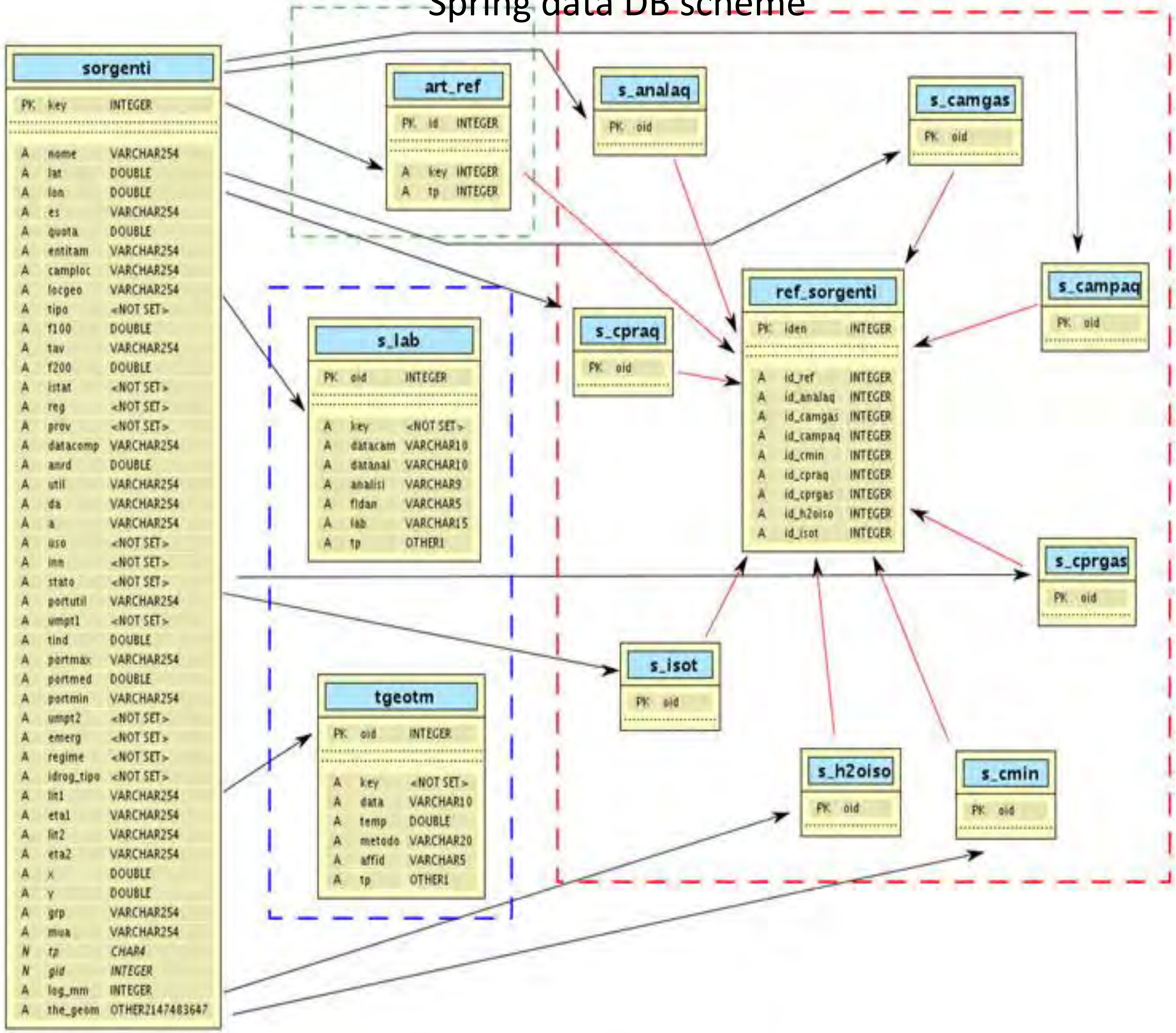
DATA COLLECTION AND ORGANIZATION

Spring data DB scheme



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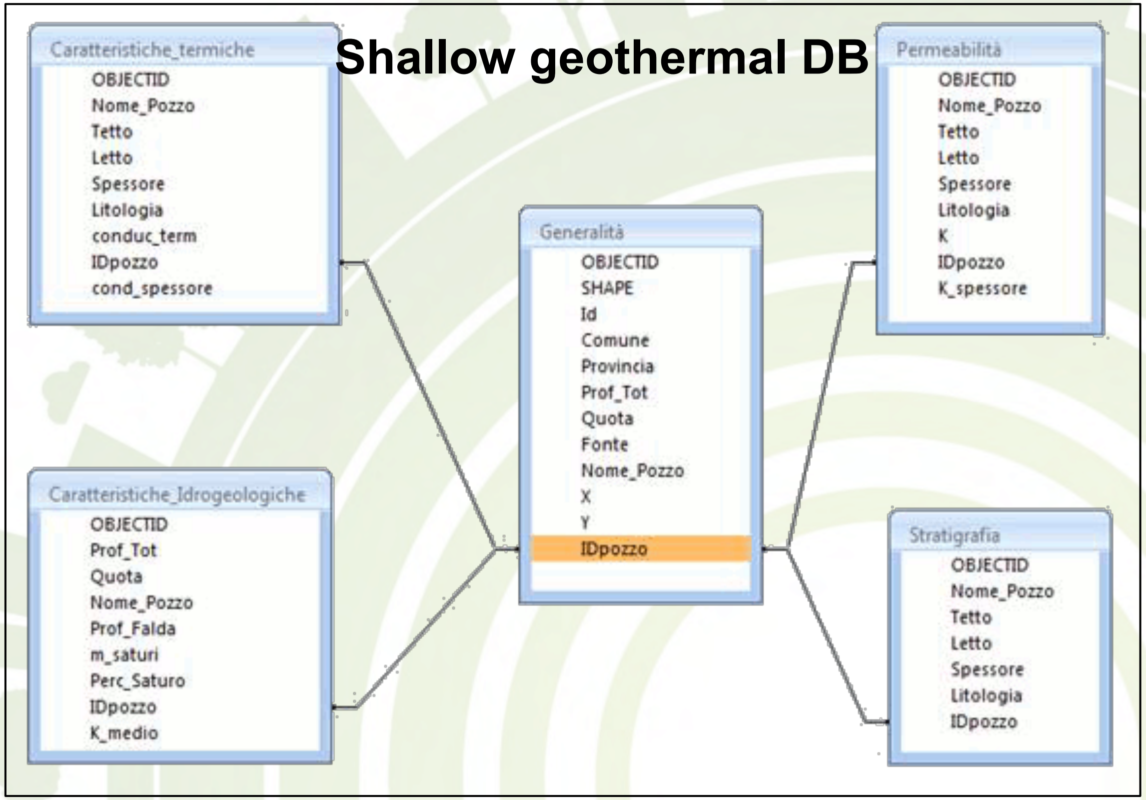
DATA COLLECTION AND ORGANIZATION



DATA COLLECTION AND ORGANIZATION

Literature Database – VIGORBIB

Home | Show All | Simple Search | Advanced Search

Login

Welcome! This database provides access to scientific literature.

main fields | Search

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Recent Changes

- added: today | yesterday | last 7 days
- edited: today | yesterday | last 7 days
- published in: 2012 | 2011 | 2010 | 2009

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Most recently added publications:

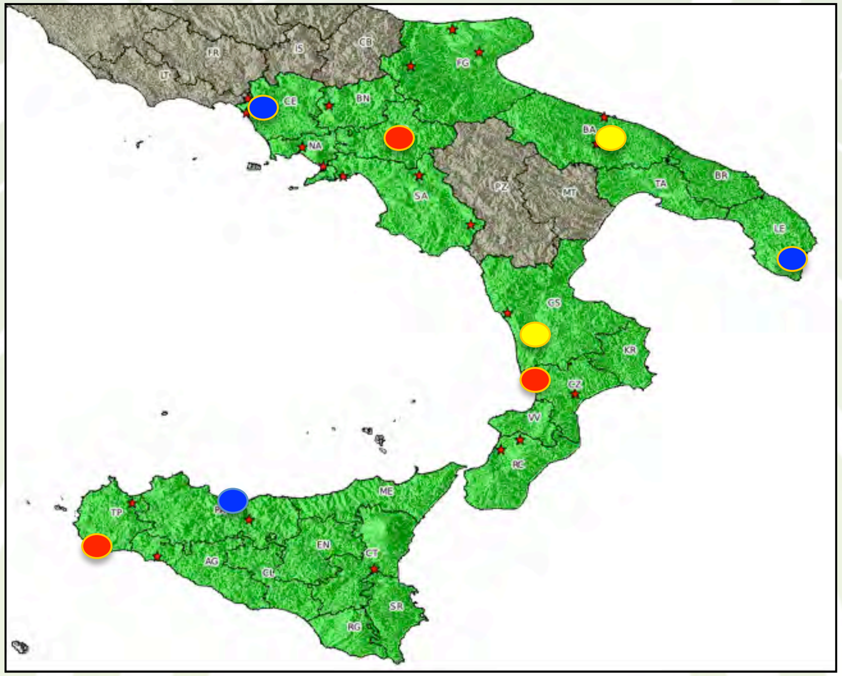
Gaudiosi, G., Alessio, G., Cella, F., Fedi, M., Florio, G., & Nappi, R. (2012). Multiparametric data analysis for seismic source identification in the Campanian area: merging of seismological, structural and gravimetric data. *Boll Geofis Teor Appl*, *53*(3), 283-298.

Rakotoarimanga, Celati, R., Taffi, L., Squarci, P., & Calore, C. (1987). SURFACE HEAT FLOW AND DEEP TEMPERATURES IN THE BRADANO TROUGH (SOUTHERN ITALY). POSSIBLE EFFECTS OF GROUNDWATER CIRCULATION. *Geothermics*, *16*(5/6), 476-485.

Maggiore, M., Nuovo, G., & Pagliarulo, P. (1996). Caratteristiche idrogeologiche e principali differenze idrochimiche delle falde sotterranee del Tavoliere di Puglia. *Mem Soc Geol It*, *51*, 669-684.

Sciannamblo, D., & Spizzico, M. (2000). Using radon for studying groundwater circulation in the Gargano promontory (Apulia, Italy). In *Tracers and Modelling in Hydrogeology (Proceedings of die TraM'2000 Conference held at Liège, Belgium, May 2000). IAHS Publ.*

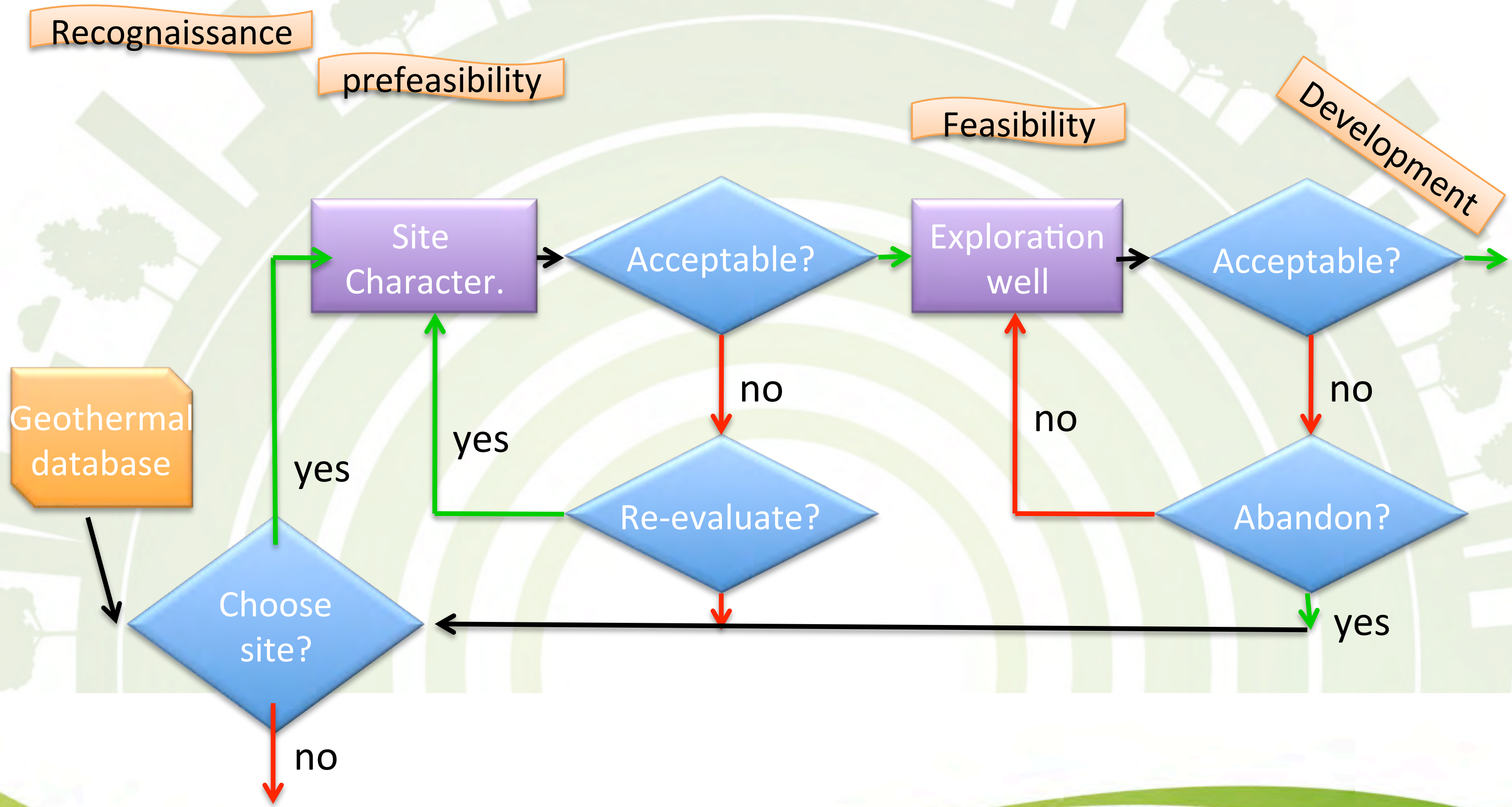
Local Assessment: Feasibility studies



- Very shallow (heat pumps)
- Shallow evaluation
- Deep evaluation

Pre-feasibility and feasibility studies, economic feasibility, cogeneration, hybrid plant proposals.

LOCAL ASSESSMENT: Feasibility studies



LOCAL ASSESSMENT: Feasibility studies

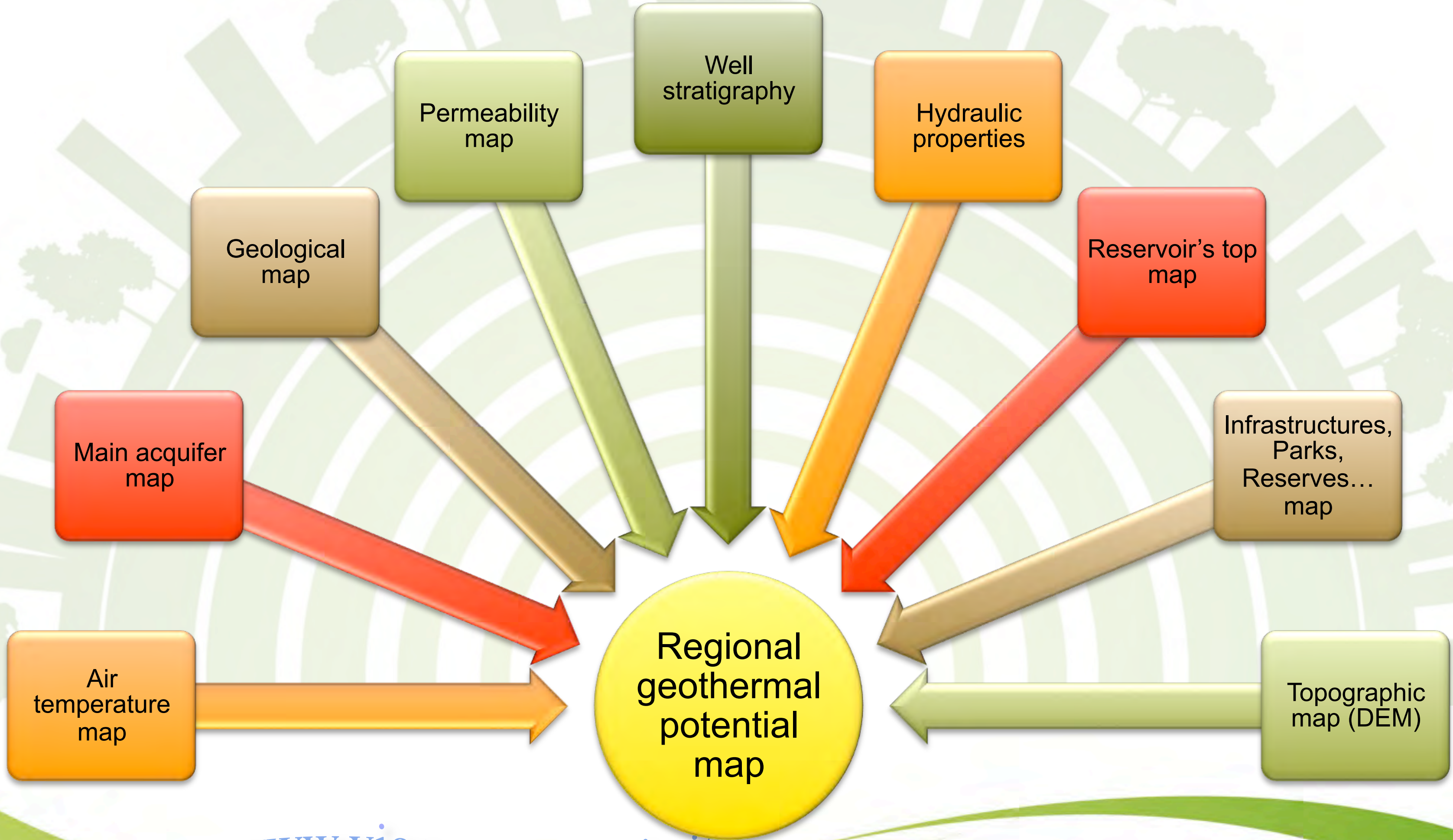
Resource evaluation, planning of plant for direct use or power production, which includes, beside the design, a sustainability analysis, authorization documents, economic analyses

- Rende: close-loop heat pump plant
- Bari: open-loop heat pump plant
- Mondragone: thermal pool and heating of public facilities
- Santa Cesarea: pasta process heating
- Lamezia Terme: waste water drying plant
- Termini Imerese: de-salinator plant
- Guardia Lombardi: Combined Heat&Power plant
- Mazara del Vallo: district heating

REGIONAL ASSESSMENT

- Regional assessment of geothermal potential
- Regional Regulation and authorization procedures

REGIONAL ASSESSMENT



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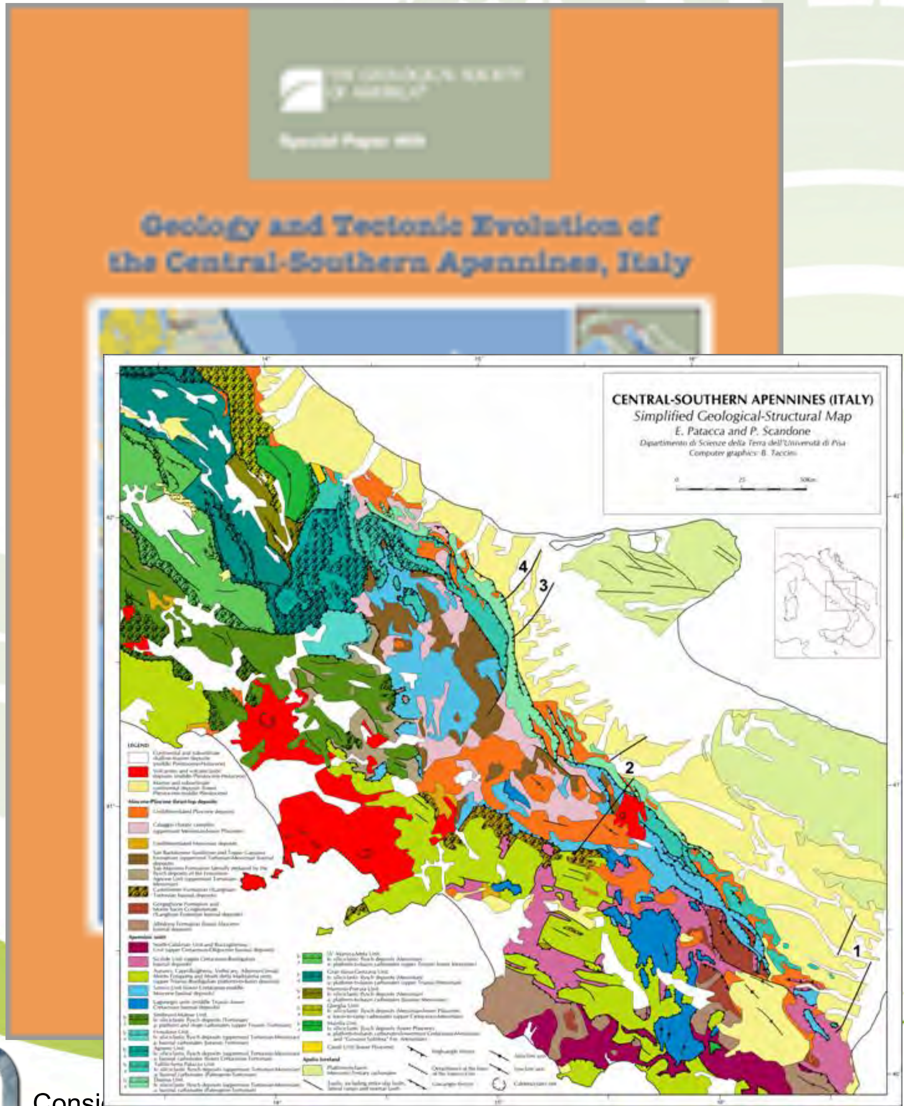
UNIONE EUROPEA Fondo Europeo di Sviluppo Regionale
QSN 2007-2013 QUADRO STRATEGICO NAZIONALE
Programma Operativo Interregionale ENERGIE RINNOVABILI E RISPARMIO ENERGETICO 2007-2013
Una scelta illuminata

GEOLOGICAL INFORMATION

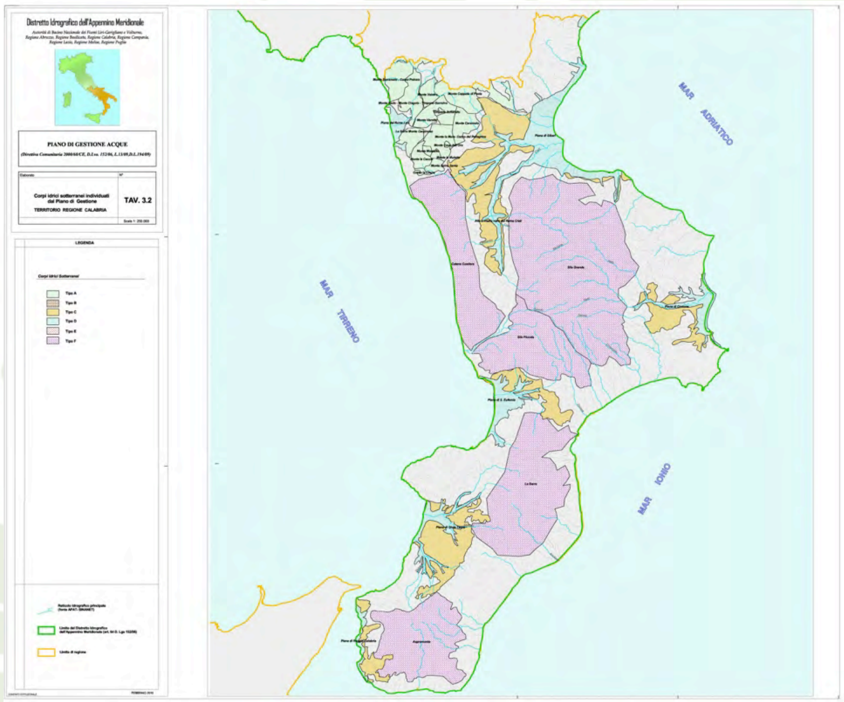


- basin layout and sediment-basement interface depth (basin contour, sediment thickness
- outlinesand thickness of granitic-crystalline formations

E.g., Top of carbonatic platform, structural models and maps from various authors

Gravimetric and magnetic data

HYDROGEOLOGICAL INFORMATION



Hydrogeological maps: shallow and deep hydrogeological units

They often lack deep characterization

ISPRA (shallow aquifer), universities (fragmented data), Regions, interregional bodies

Consiglio Nazionale delle Ricerche
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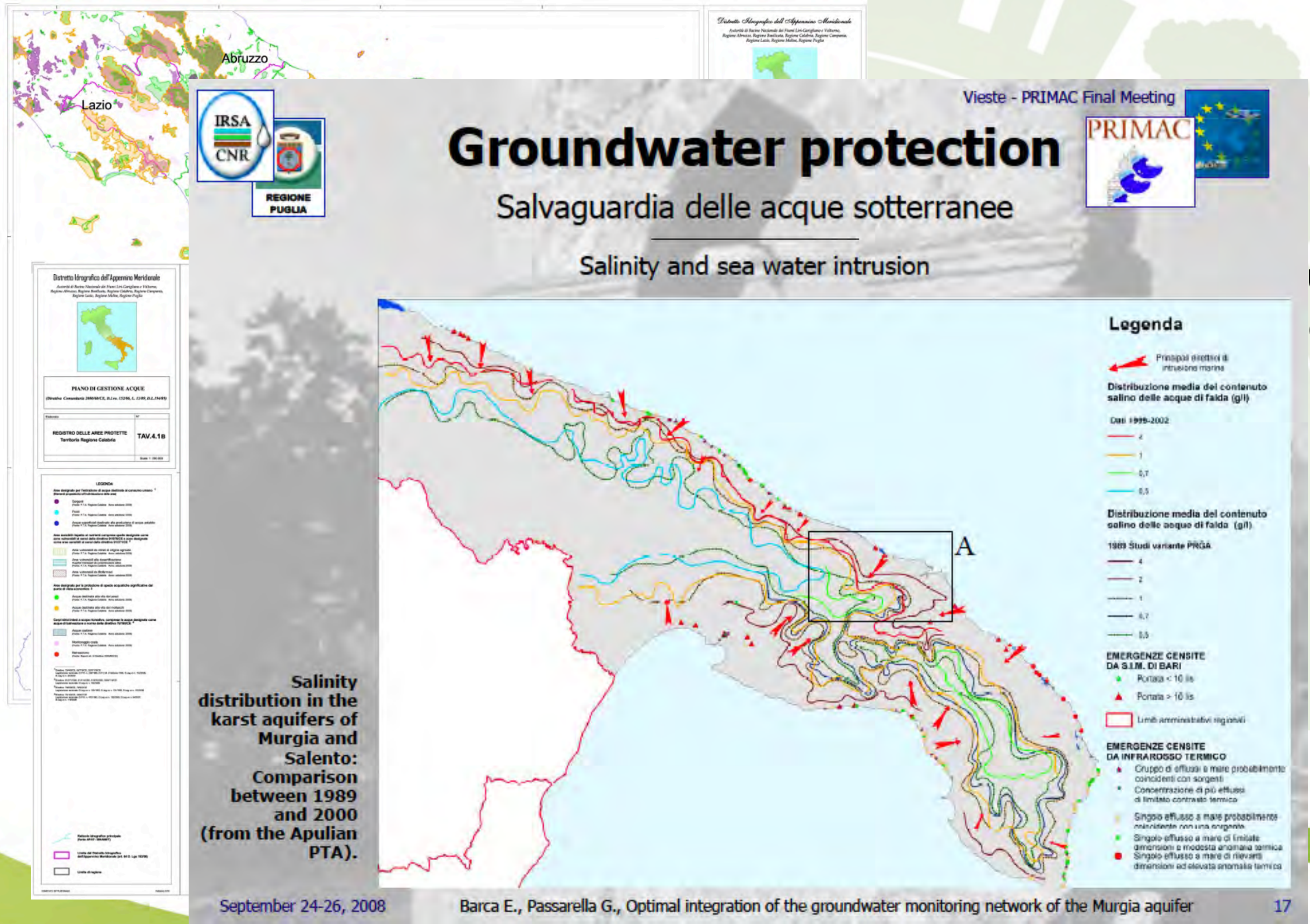
RESTRICTION, LIMITATION



us sources
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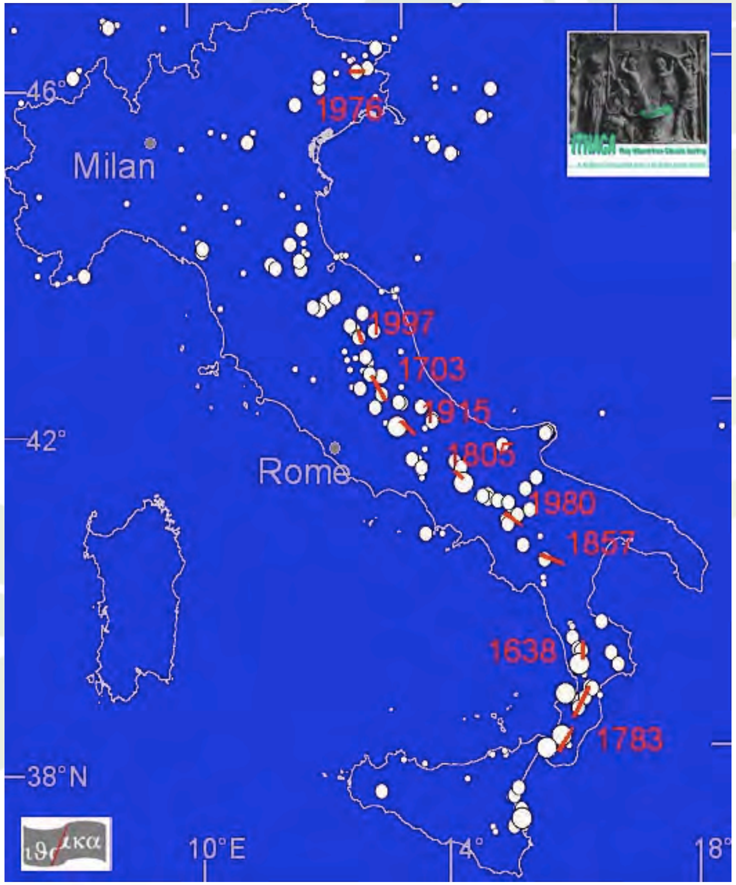
Restriction, limitation



Data from the ITHACA project
(ITaly HAzard from CApable faults)
developed by ISPRA
(Italian National Institute for
Environmental Protection and Research)

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SHALLOW GEOTHERMAL POTENTIAL

Temperature distribution at surface

Air temperature data, topography, latitude

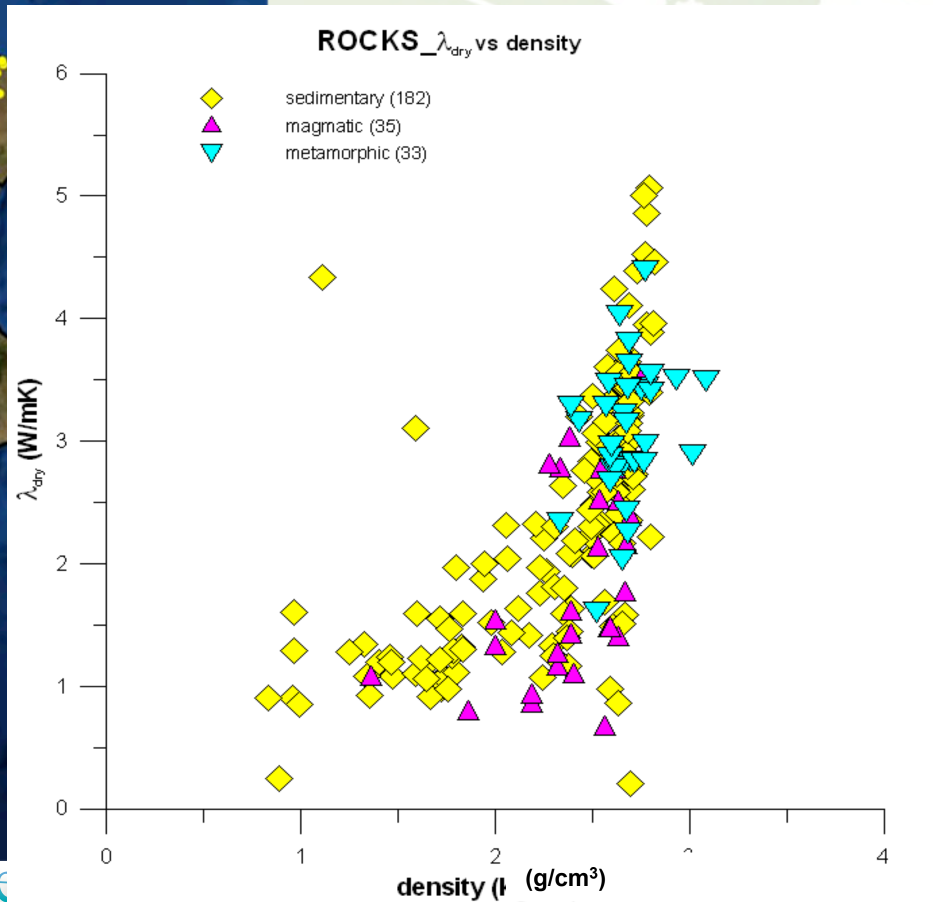
Thermal conductivity distributions

Geological maps, hydraulic and stratigraphic well data, conductivity from literature and lab analyses

Exchange energy

Ground Temperature, reference volume, reference plant

SHALLOW GEOTHERMAL POTENTIAL



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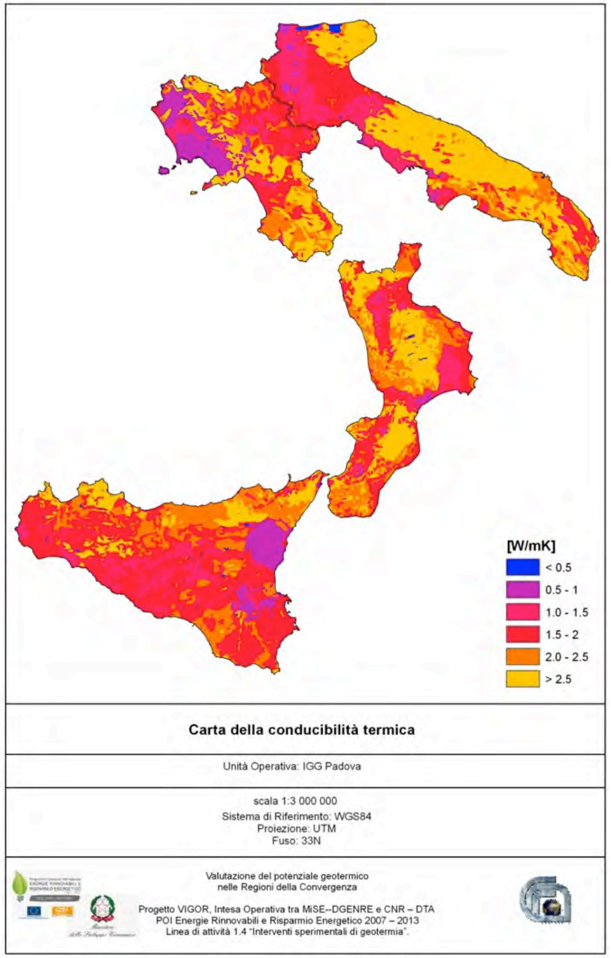
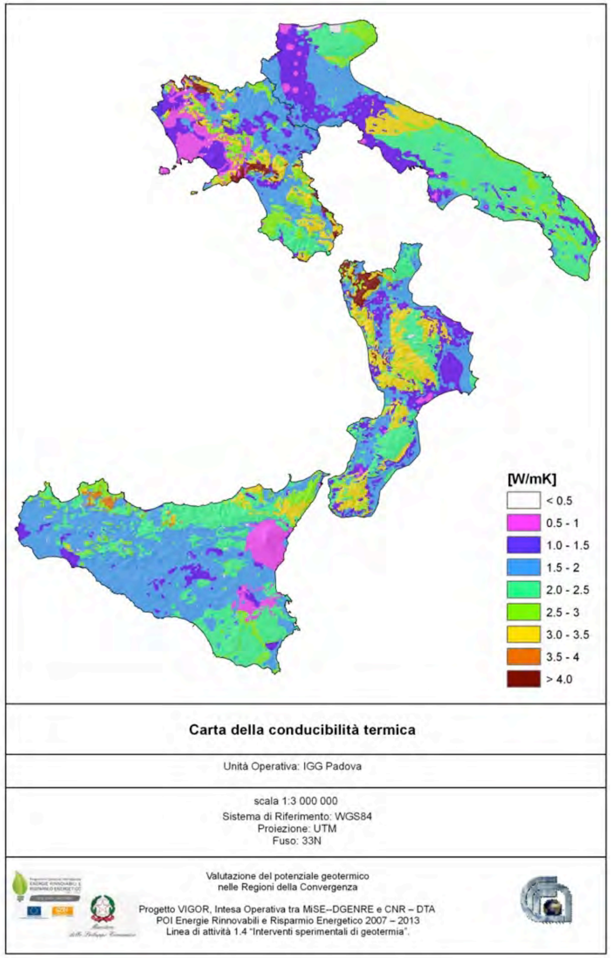
SHALLOW GEOTHERMAL POTENTIAL





SHALLOW GEOTHERMAL POTENTIAL

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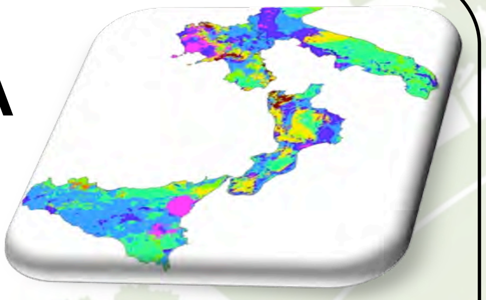

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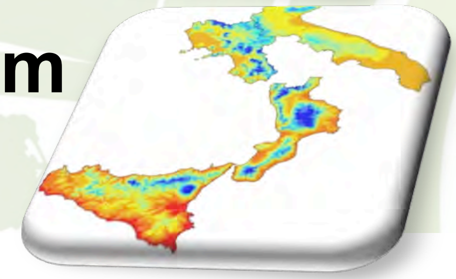
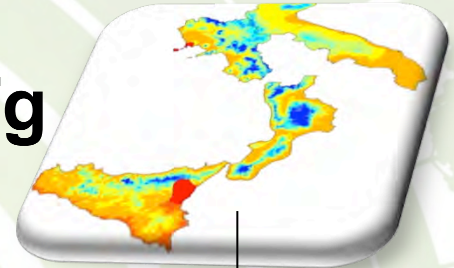
Tm



$$Tg = Tm + \frac{\Phi}{\lambda} *L/2$$

Fourier's Law
L = 100 m

Tg



Thermal energy that can be exchanged by a unit volume of ground for a reference GSHP plant

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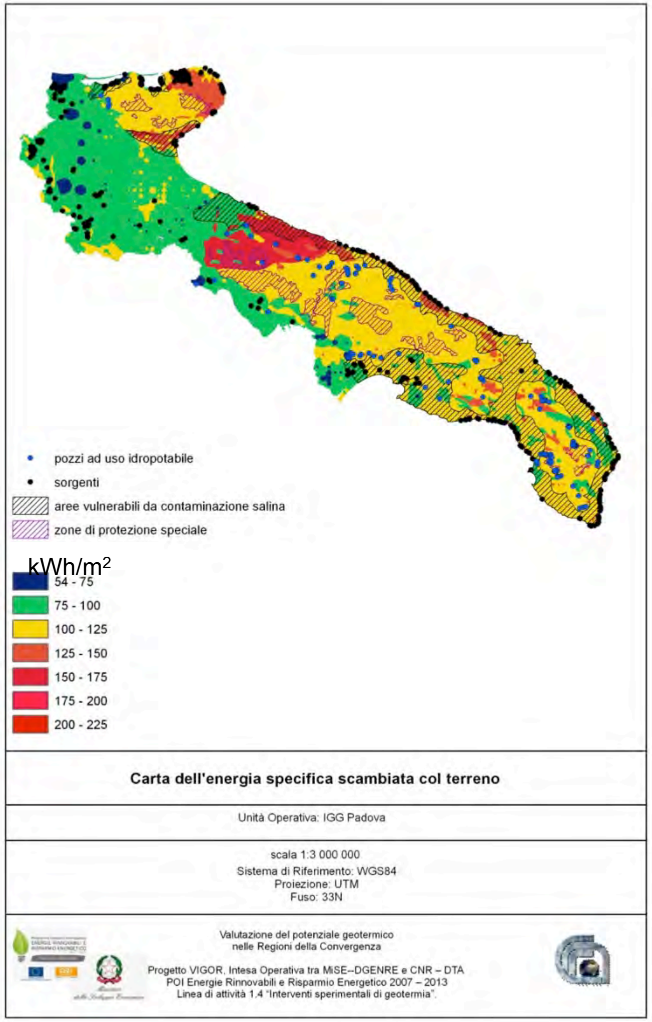
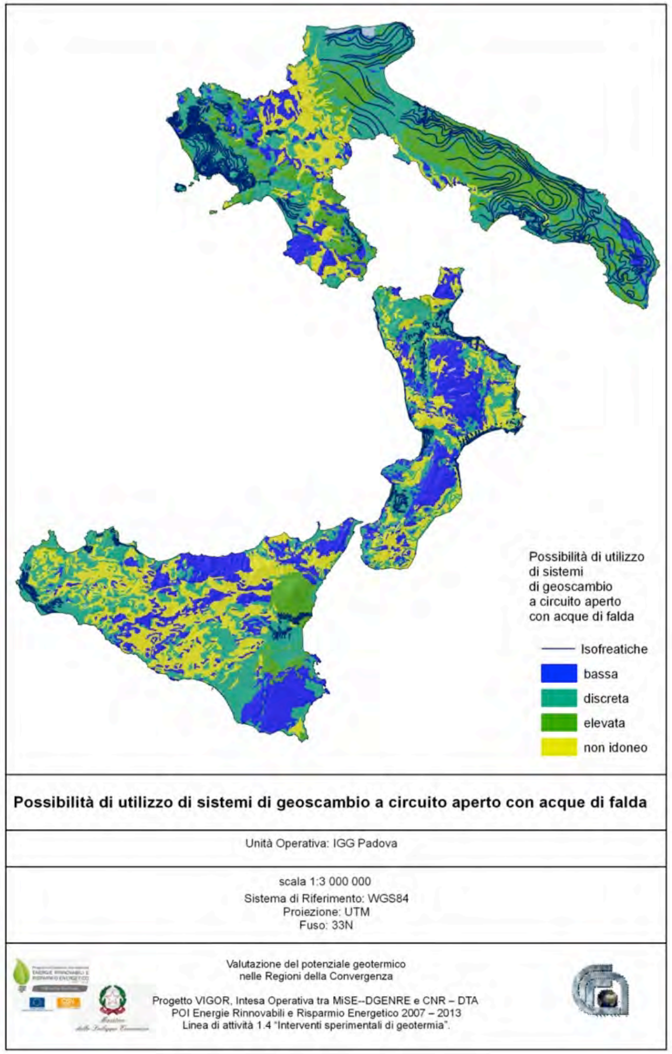
SHALLOW GEOTHERMAL POTENTIAL





VIGOR THERMOGIS

TNO innovation for life

VIGOR ThermoGIS works both in **2D** and in **3D**

- Data input is the result of a **team** of specialists: geologist, hydro-geologist, geo-chemist, geophysicists, ...
- **Volumetric** method assessment
- Include **Montecarlo calculation** to incorporate the effects of **uncertainty**

Output maps: temperature maps at various depth, technical potential for power and heat applications

Heat In Place [PJ/km²]

It is the maximum theoretically extractable heat in the reservoir per unit volume (thickness = 100 m)

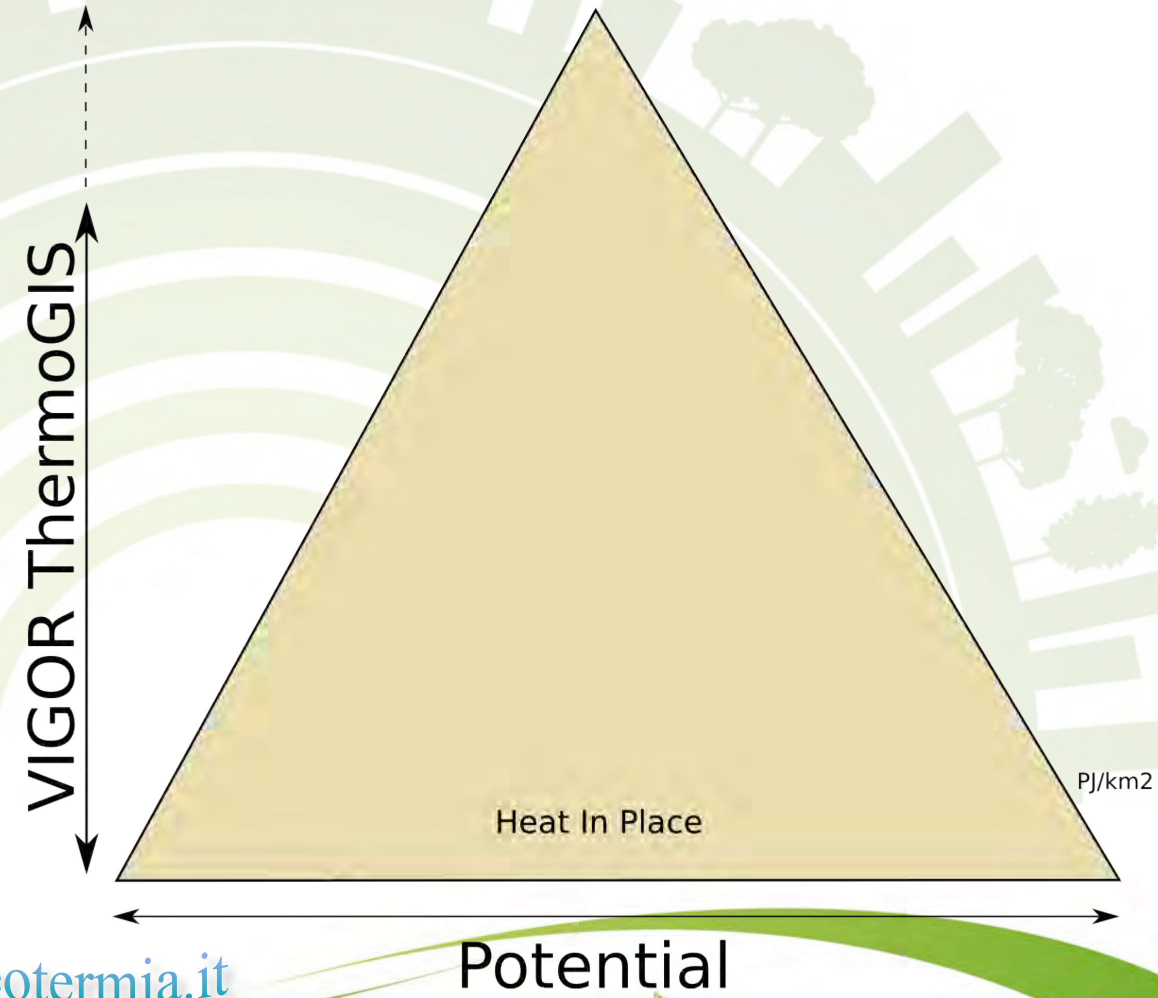
$H = V \times \boldsymbol{\rho}_{rock} \times cp_{rock} \times (Tx - Ts) \times 10^{-15}$

Tx = Temperature @ depth

Ts = Temperature @ surface

$\boldsymbol{\rho}_{rock} = 2700\ kg/m^3$

$cp_{rock} = 1000\ J/kg\ k$



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Dipartimento Terra e Ambiente

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ENERGIE RINNOVABILI E RISPARMIO ENERGETICO
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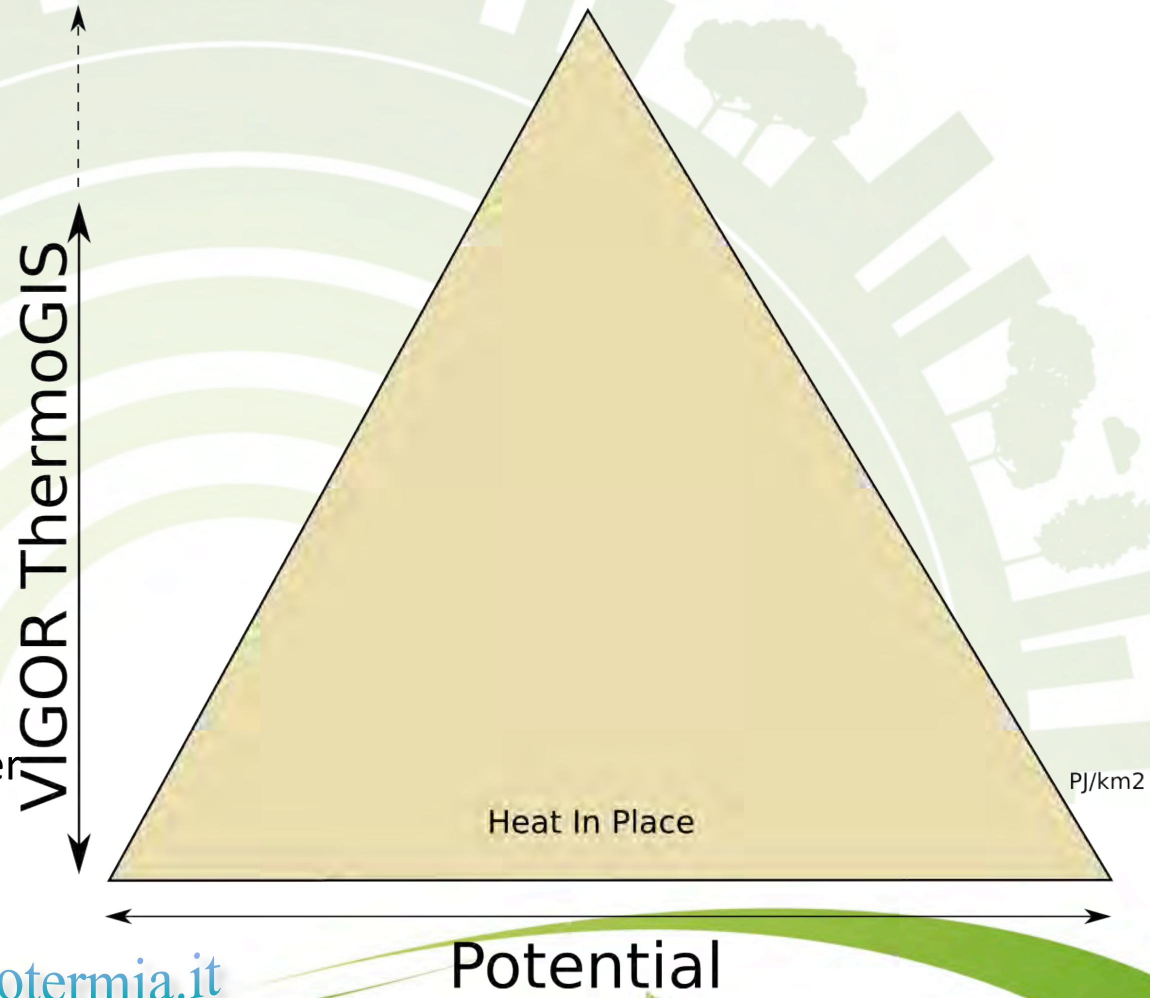
Una scelta illuminata

VIGOR ThermoGIS

Heat In Place [PJ/km^2]



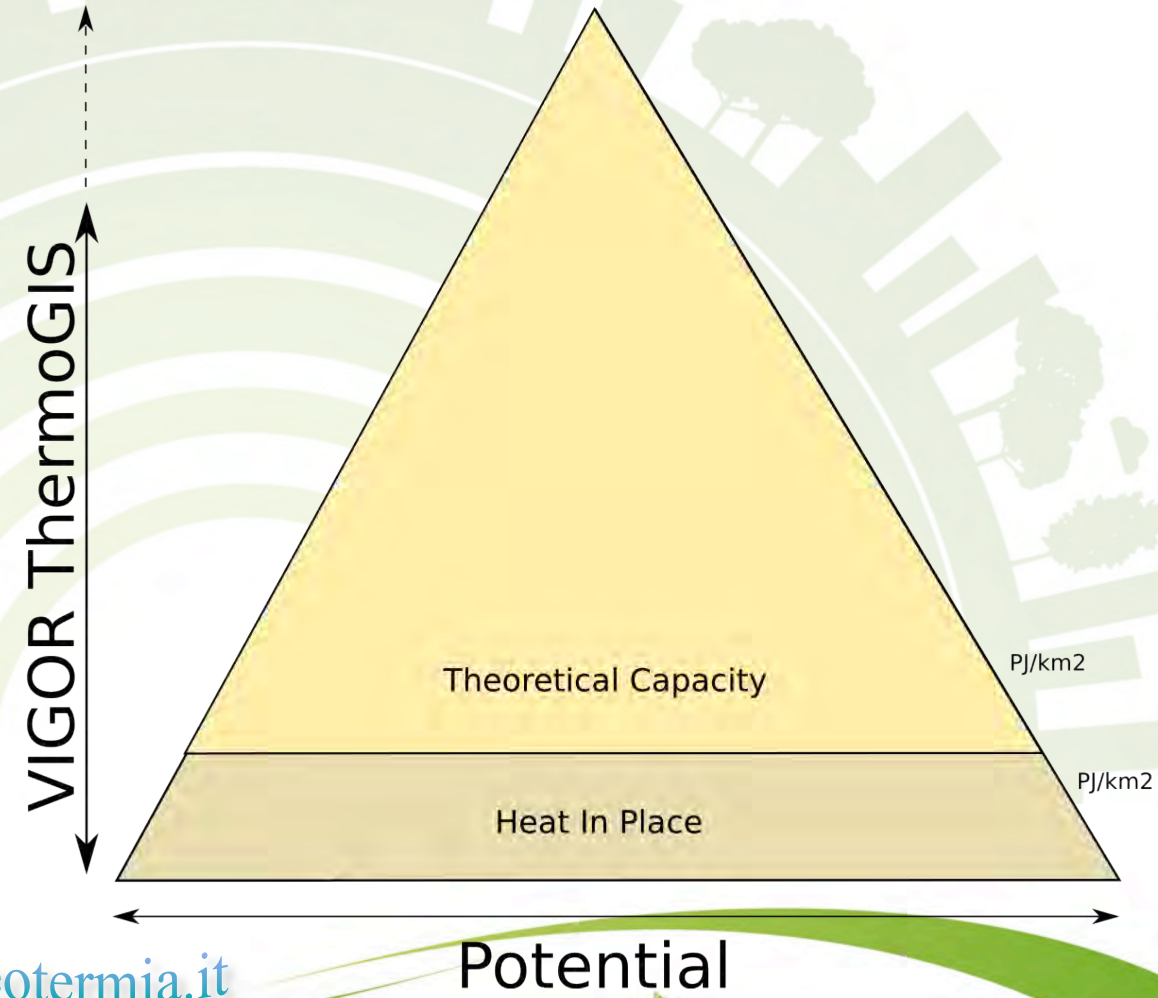
It is the maximum theoretically extractable heat in the reservoir per unit volume (thickness = 100 m)

VIGOR THERMOGIS

Theoretical Capacity [PJ/km^2]

Thermal Energy produced by a technology per unit volume (TC=H x technology efficiency)

H is the maximum theoretically extractable heat in the reservoir per unit volume (thickness = 100 m)



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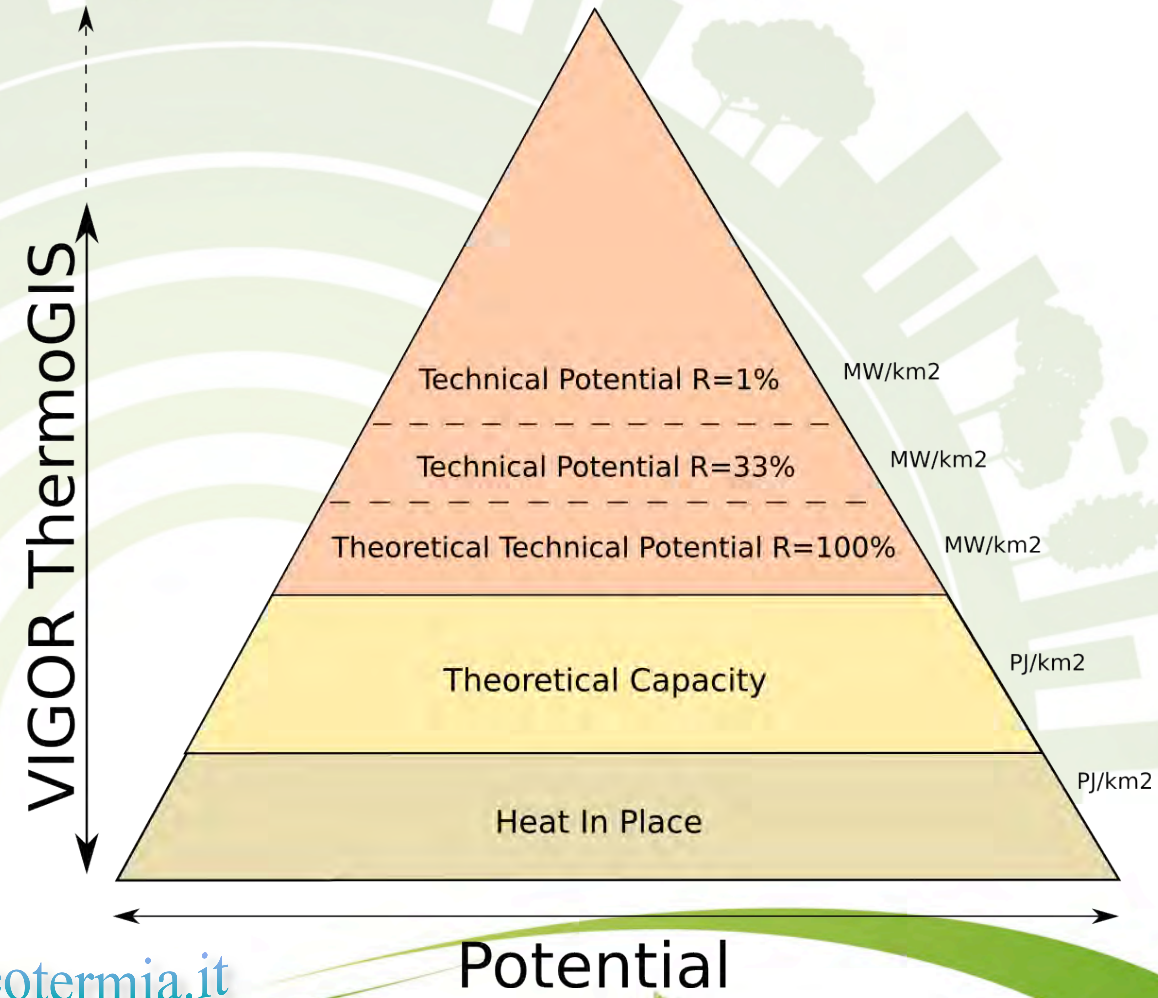
VIGOR THERMOGIS

Theoretical and Technical Potential [MW/km²]

Geothermal Potentials for a lifecycle of 30 years and different Recovery Factors
(GP=TC x R / 30 years)

Thermal Energy produced by a technology (TC=H x technology efficiency) per unit volume

H is the maximum theoretically extractable heat in the reservoir per unit volume (thickness = 100 m)



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VIGOR ThermoGIS

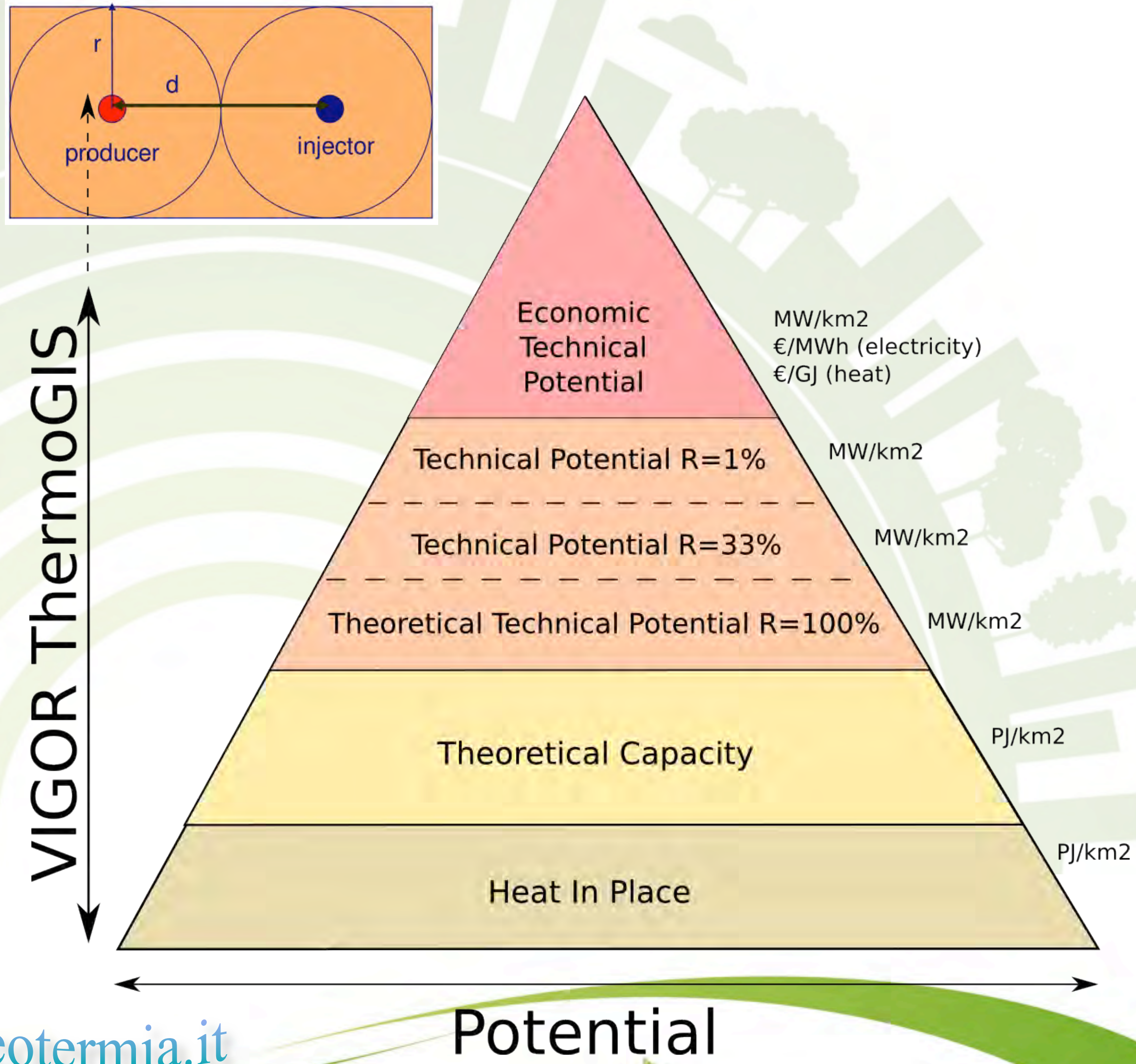
Economic Technical Potential [MW/km^2]

Technical Potential for LCOE < threshold (200 €/MWh power, 9 €/GJ heat) and using expected flowrate from a doublet system

Geothermal Potentials for a lifecycle of 30 years and different Recovery Factors (GP=TC x R / 30 years)

Thermal Energy produced by a technology (TC=H x technology efficiency) per unit volume

H is the maximum theoretically extractable heat in the reservoir per unit volume (thickness = 100 m)



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Levelized Cost Of Energy [LCOE, €/MWe, €/JG]

Calculated for power, district heating and direct heat uses

Depends on:
- Drilling cost (depth, stimulation, pump, ...)
- Economic lifetime
- Flowrate & temperature
- Power surface facilities (O&M, plant investiment, …)
- Complementary electricity/heat sales
- Economic factors (inflation, interest rate on debit, tax)

	Power product.	District heating	Direct uses
Tmin	120	80	45
T-reinject	80	40	35
Economic Model	power	heat	heat
LCOE <	200 €/MWe	9 €/GJ	9 €/GJ

Flowrate depends on transmissivity, delta pressure applied at reservoir level and viscosity

Specific routines redistributes the permeability according to Montecarlo simulation

From transmissivity average on drilled interval, cumulative probability of expected flowrate is considered

VIGOR ThermoGIS

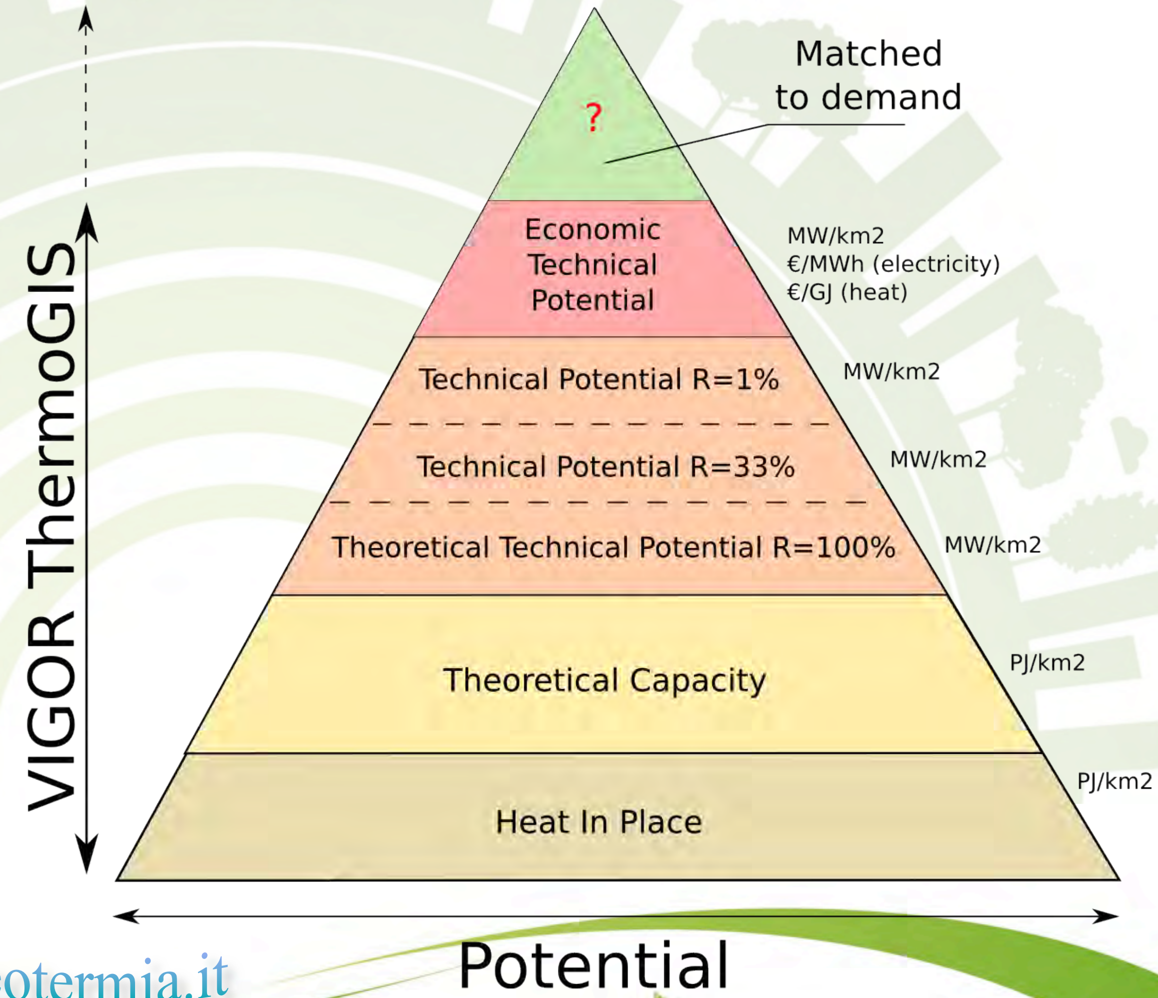
Match Resource to energy demand

Technical Potential for LCOE < threshold and expected flowrate from a doublet system

Geothermal Potentials for a lifecycle of 30 years and different Recovery Factors (GP=TC x R / 30 years)

Thermal Energy produced by a technology (TC=H x technology efficiency) per unit volume

H is the maximum theoretically extractable heat in the reservoir per unit volume (thickness = 100 m)



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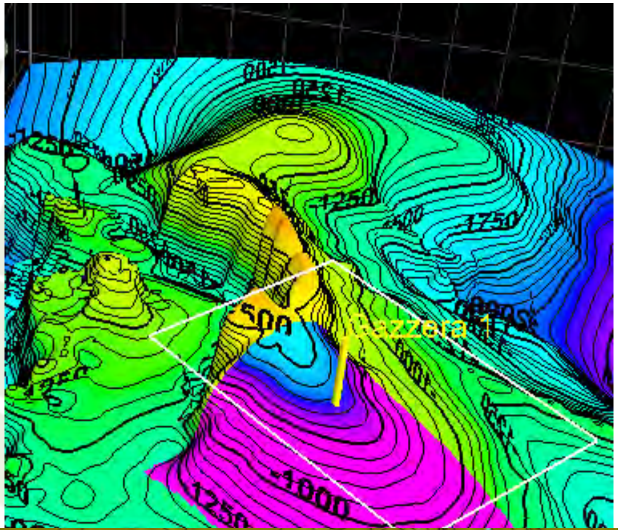
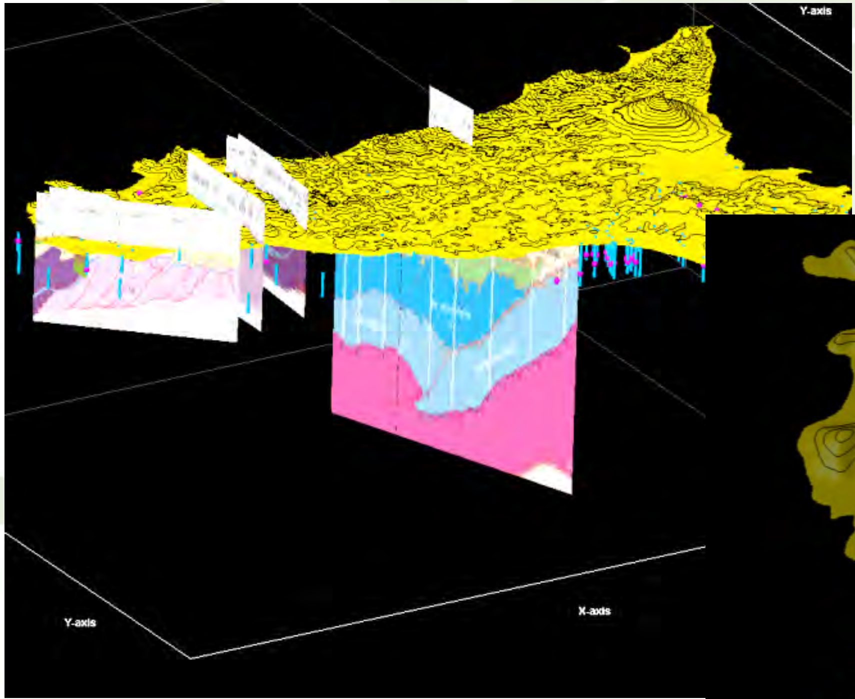
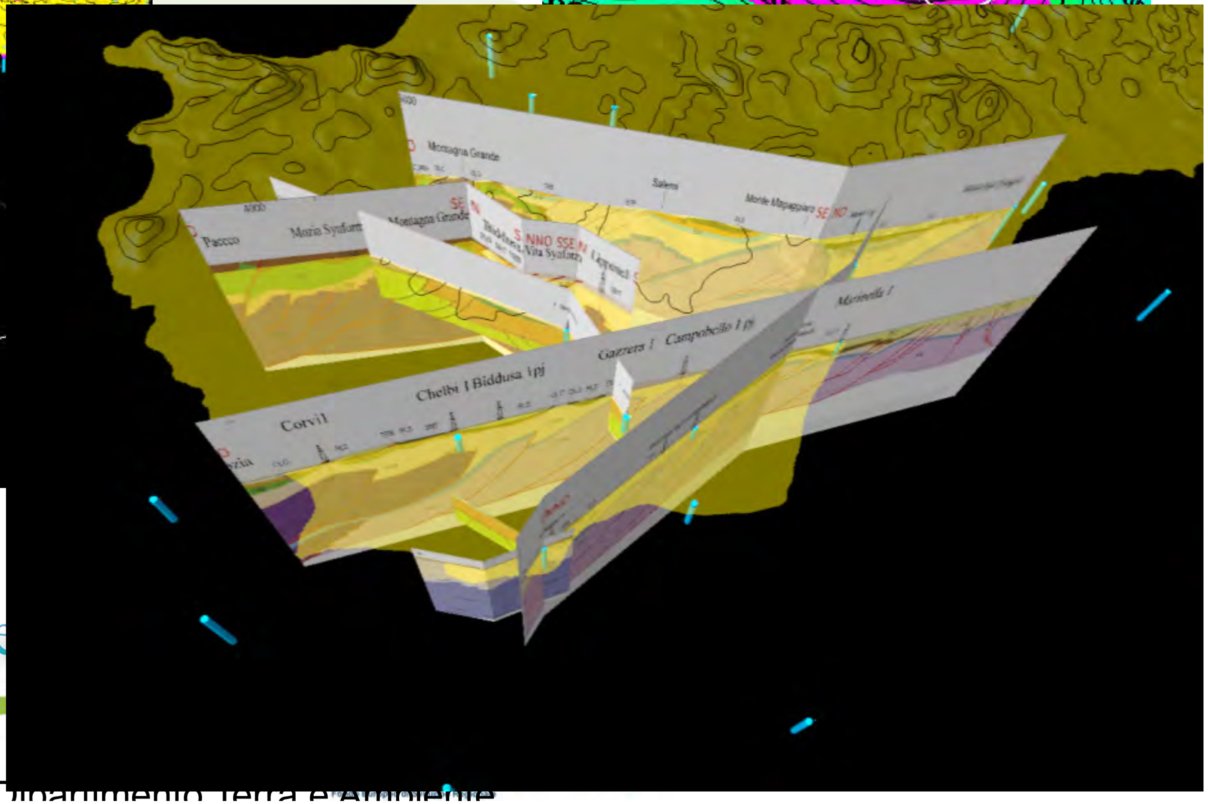
GEOLOGICAL MODELLING







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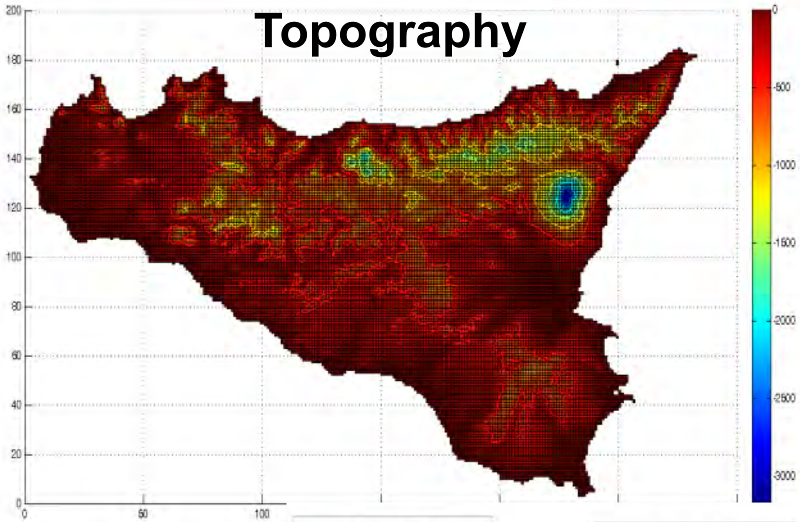
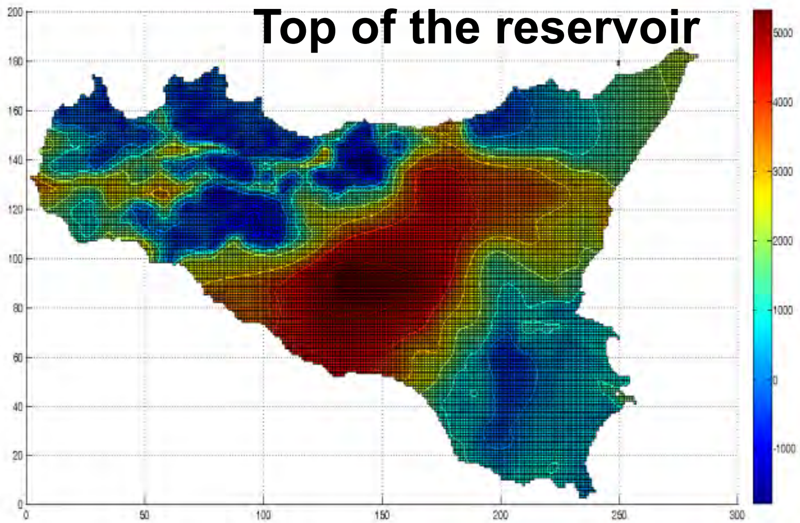
Dipartimento Terra e Ambiente

THERMAL MODELLING

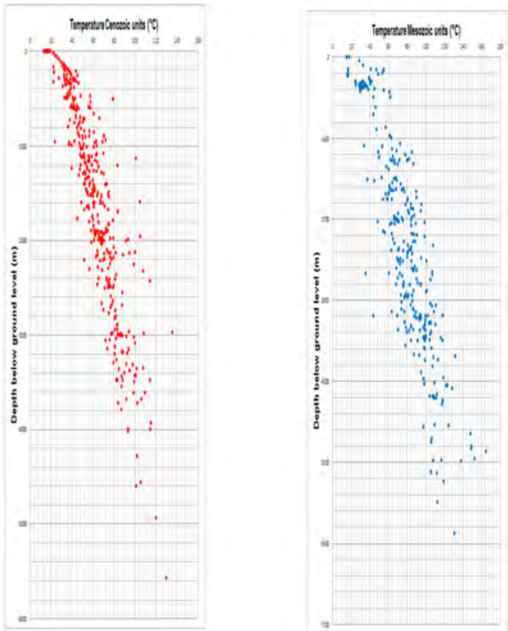
Topography



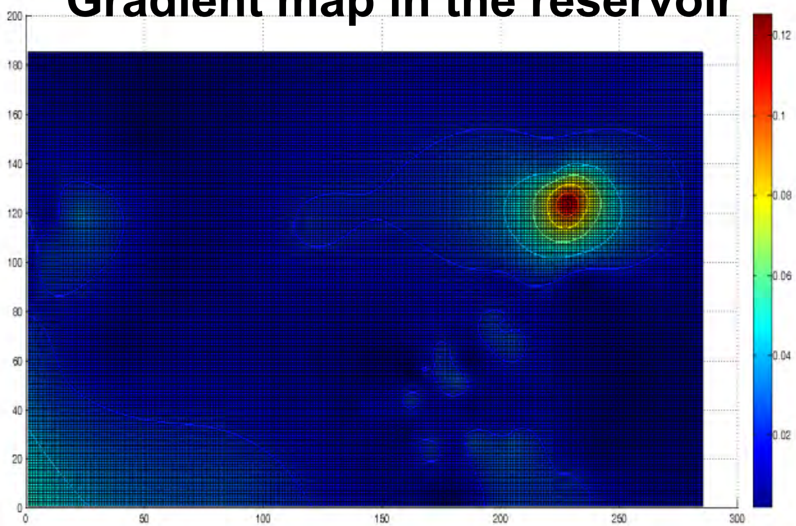
Top of the reservoir



Temperature gradient in cover (red) and reservoir (blue) units



Gradient map in the reservoir



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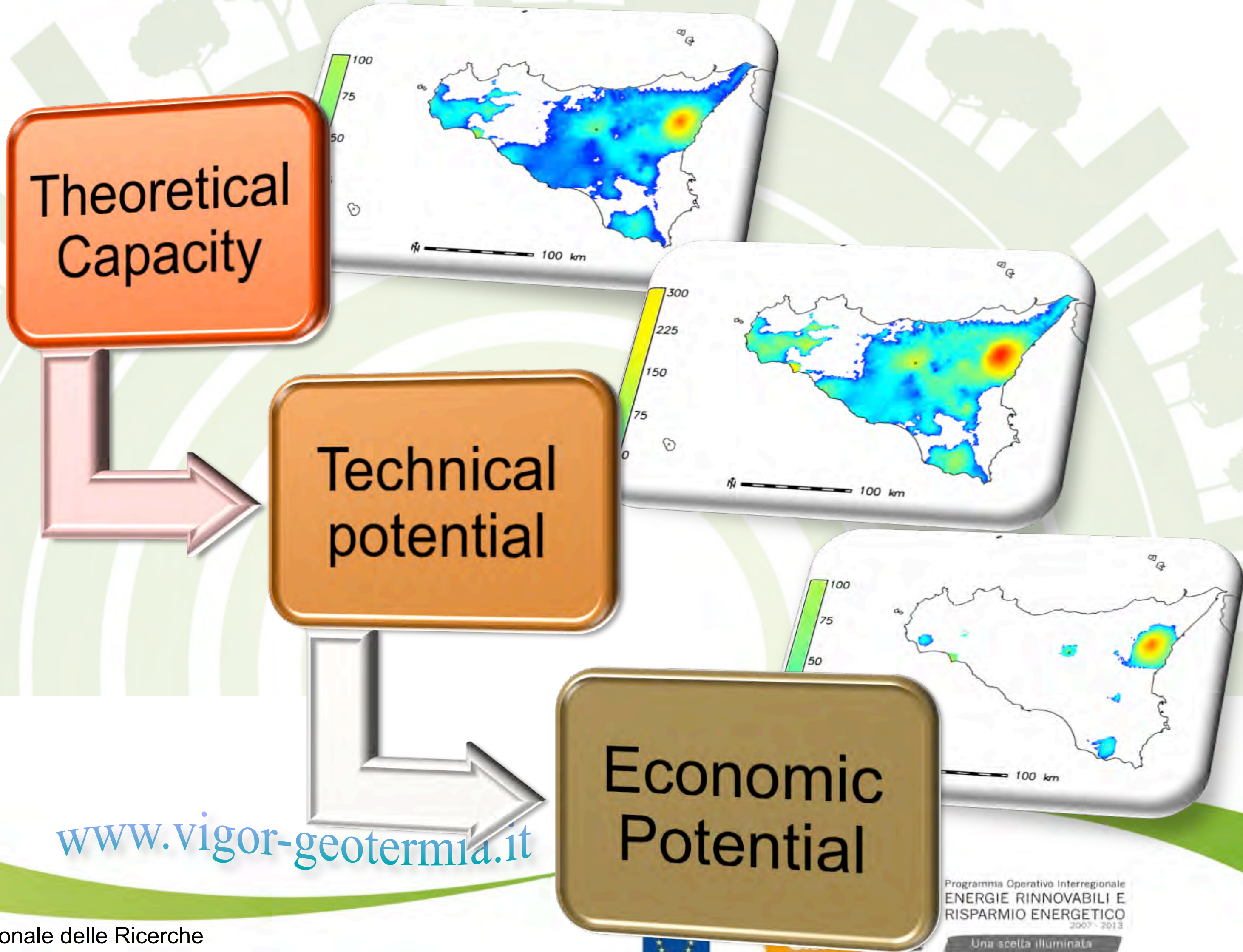
VIGOR THERMOGIS
POWER PRODUCTION



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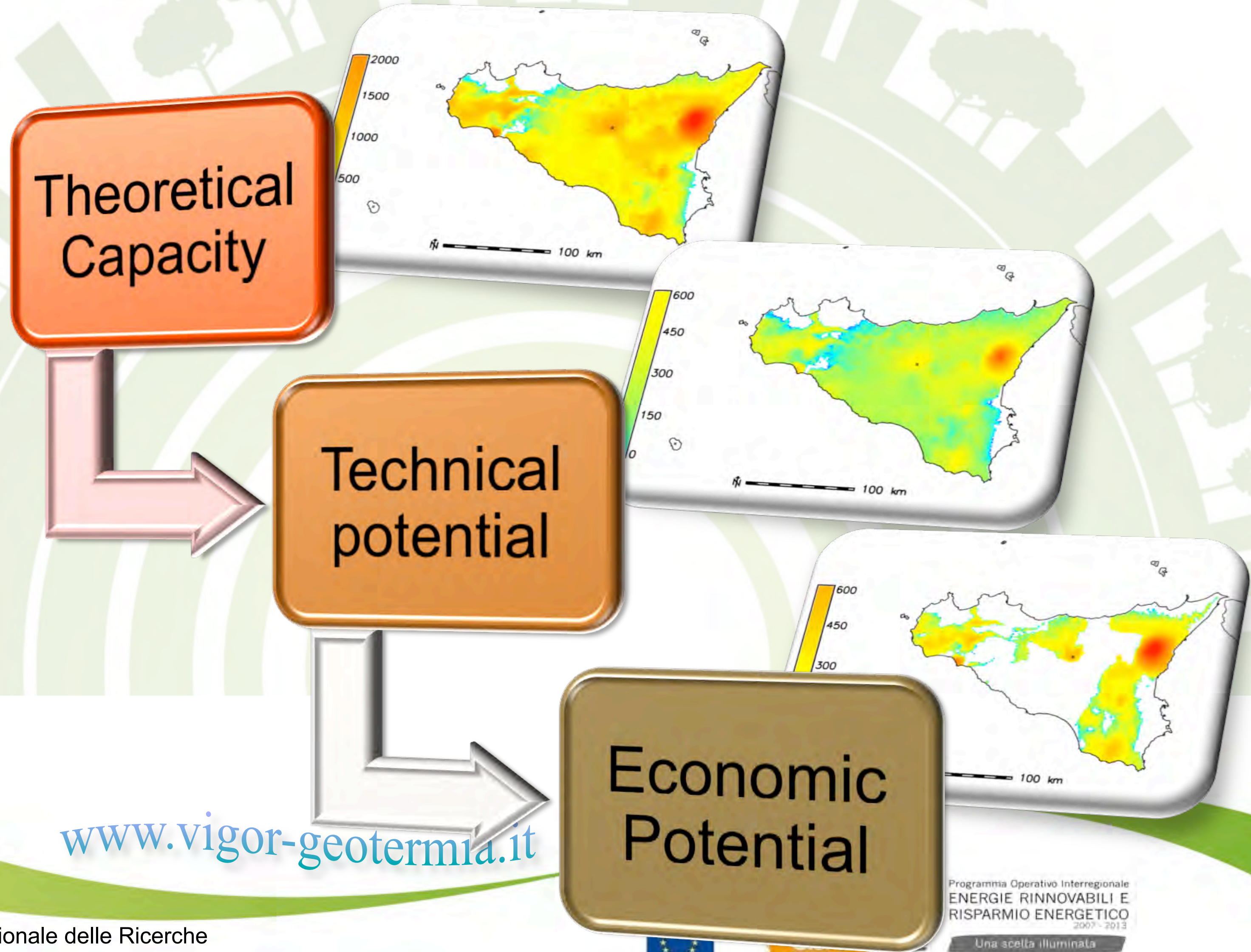
VIGOR ThermoGIS District Heating



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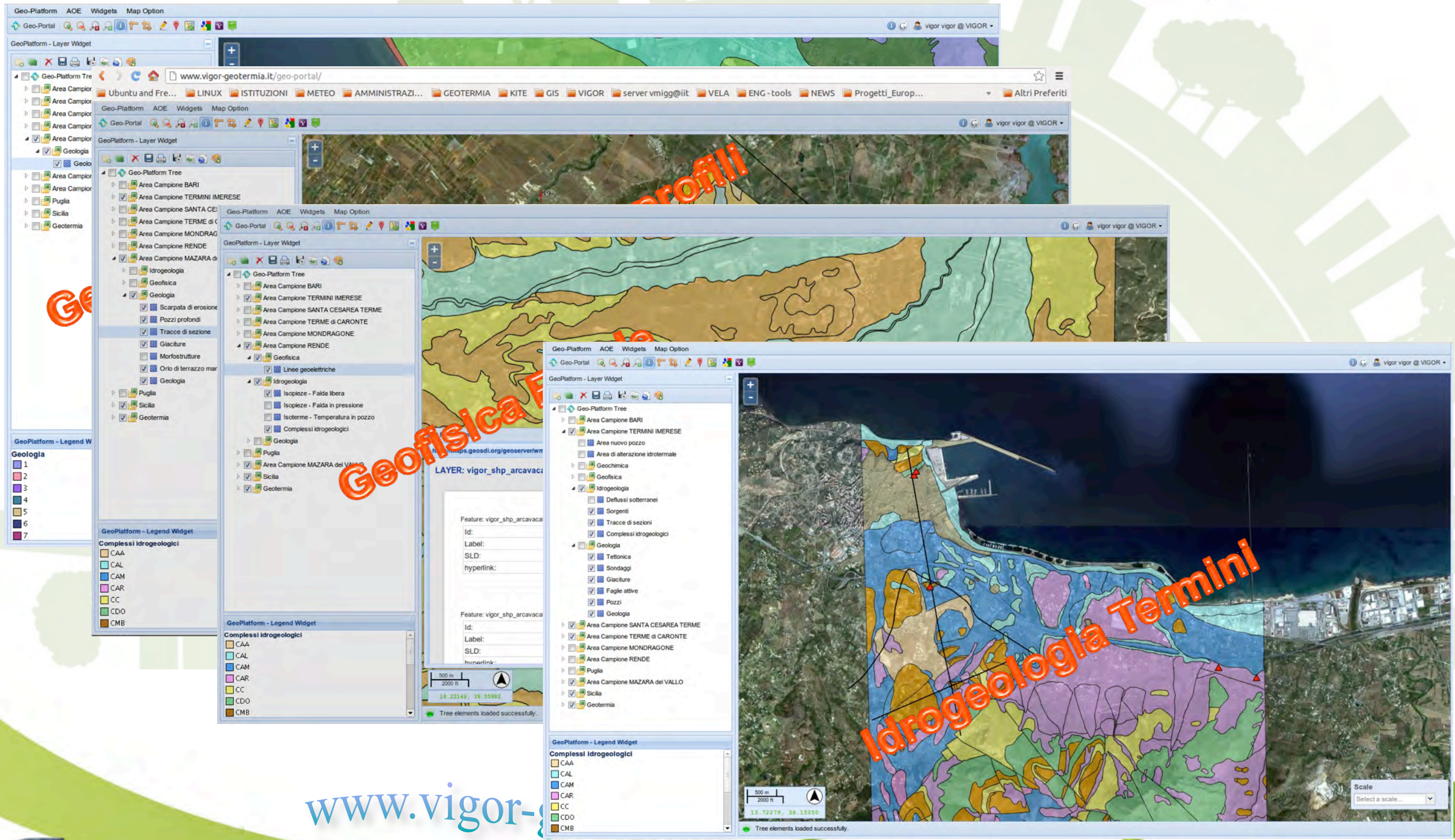
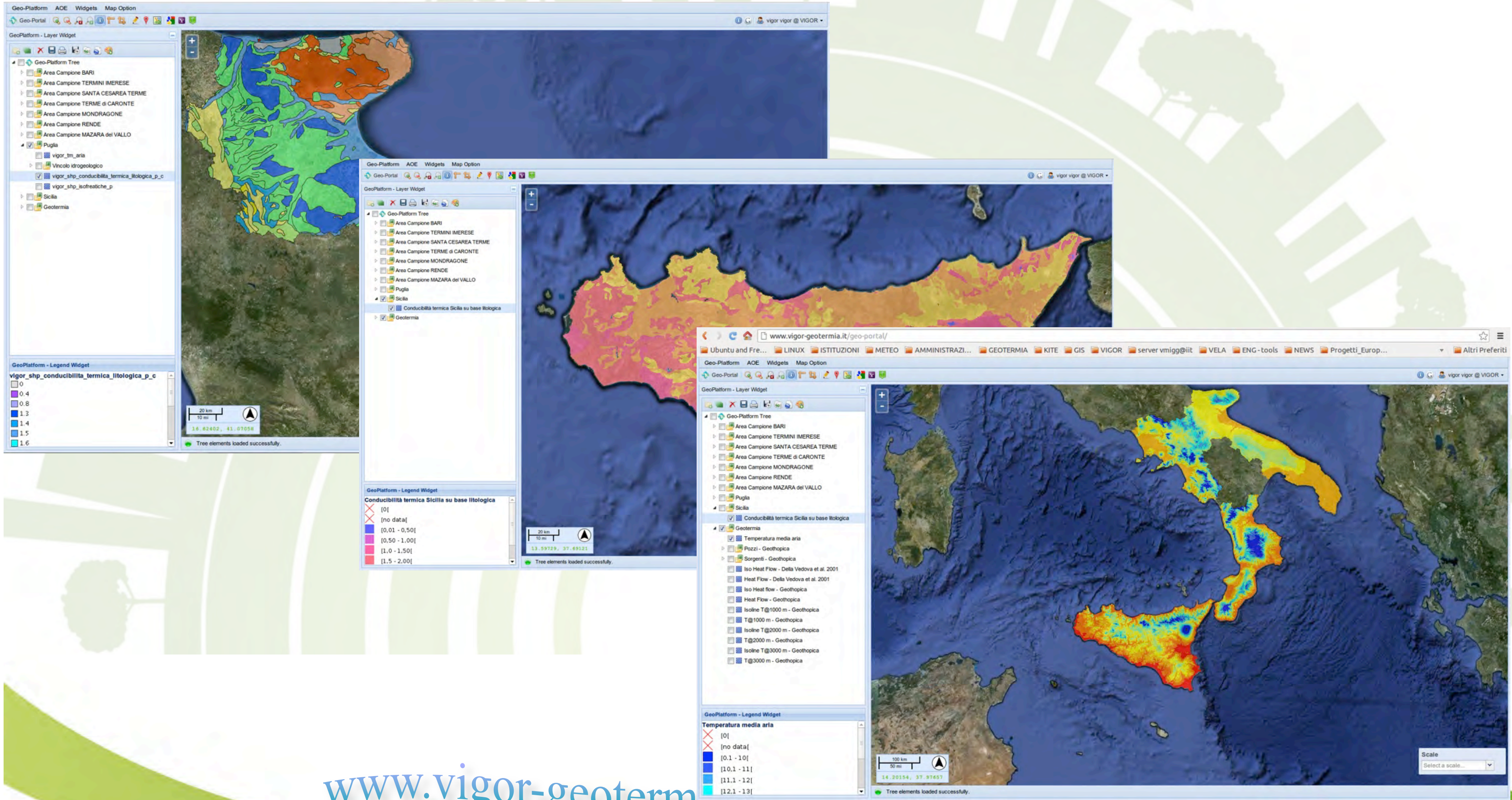
DATA COLLECTION AND ORGANIZATION
WEBMAPS



DATA COLLECTION AND ORGANIZATION
WEBMAPS



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Main features

Potential recovered in the four Regions, to balance the four

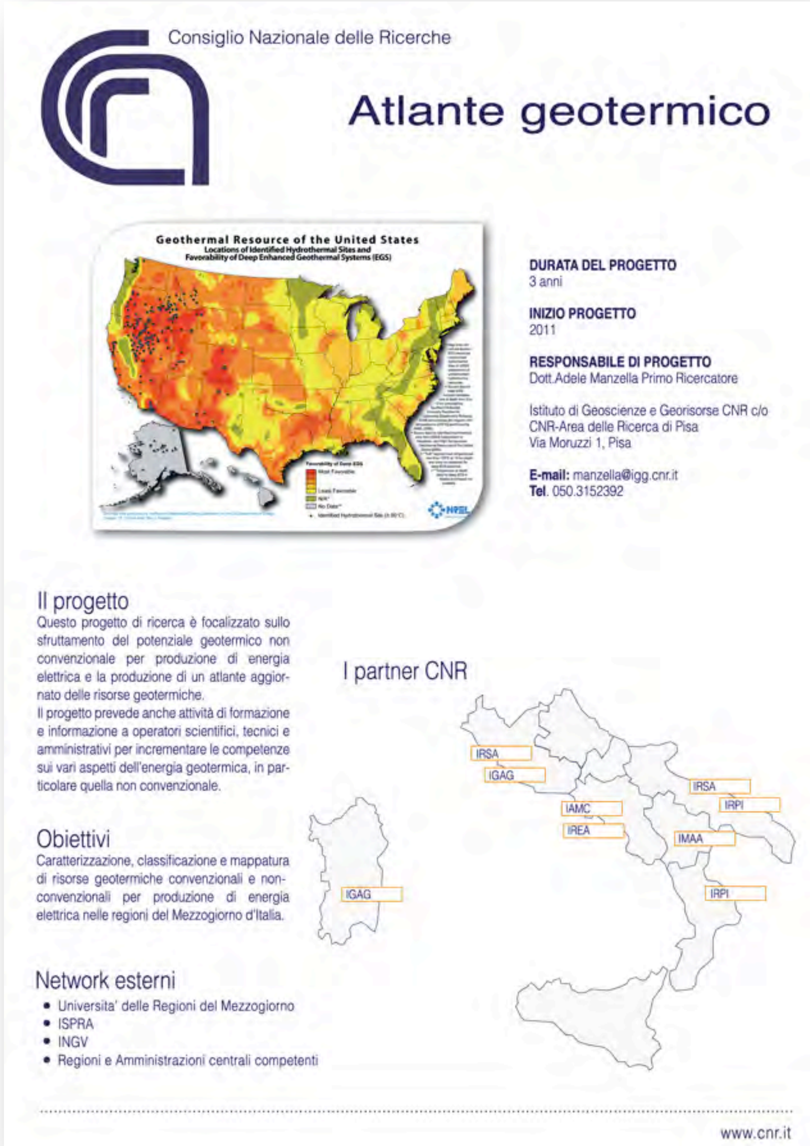
Coverage of application (direct uses may cover wide sectors of the territory, creating the required wide involvement in terms of occupation, market, business)

- Complete system approach **(from data to regulation to feasibility);**
- Cooperation **(Ministry-CNR and then CNR-research institutes and universities);**
- Project management quality **(integrated approach environment/ territories/technologies);**
- Promotion of local uses**, by comprehensive presentation of opportunities;**
- Identification of proper financial opportunities**, from incentives to financial support.**

GEOTHERMAL ATLAS

ATLAS of conventional and unconventional geothermal resources in the italian southern regions

It provides an update of resource Atlas as defined on 1992,
and includes assessment down to 10 km, also for UGR.



Consiglio Nazionale delle Ricerche

Atlante geotermico

Geothermal Resource of the United States

DURATA DEL PROGETTO
3 anni

INIZIO PROGETTO
2011

RESPONSABILE DI PROGETTO
Dott.Adele Manzella Primo Ricercatore

Istituto di Geoscienze e Georisorse CNR c/o
CNR-Area delle Ricerca di Pisa
Via Moruzzi 1, Pisa

E-mail: manzella@igg.cnr.it
Tel. 050.3152392

Il progetto

Questo progetto di ricerca è focalizzato sullo sfruttamento del potenziale geotermico non convenzionale per produzione di energia elettrica e la produzione di un atlante aggiornato delle risorse geotermiche.
Il progetto prevede anche attività di formazione e informazione a operatori scientifici, tecnici e amministrativi per incrementare le competenze sui vari aspetti dell'energia geotermica, in particolare quella non convenzionale.

Obiettivi

Caratterizzazione, classificazione e mappatura di risorse geotermiche convenzionali e non-convenzionali per produzione di energia elettrica nelle regioni del Mezzogiorno d'Italia.

I partner CNR

Network esterni

- Universita' delle Regioni del Mezzogiorno
- ISPRA
- INGV
- Regioni e Amministrazioni centrali competenti

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GEOTHERMAL ATLAS

Atlas of GS, EGS and UGS, similar to those provided in other countries,

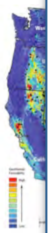
Realization of Data Centers

Evaluation of environmental issues and ways of reduction

Information, promotion and training

GEOTHERMAL ATLAS

Atlas of GS, EGS and UGS, taking into consideration those provided in other countries,



- *EGS*;
- *Geopressurized systems*;
- *Magmatic systems*;
- *Supercritical fluid conditions*

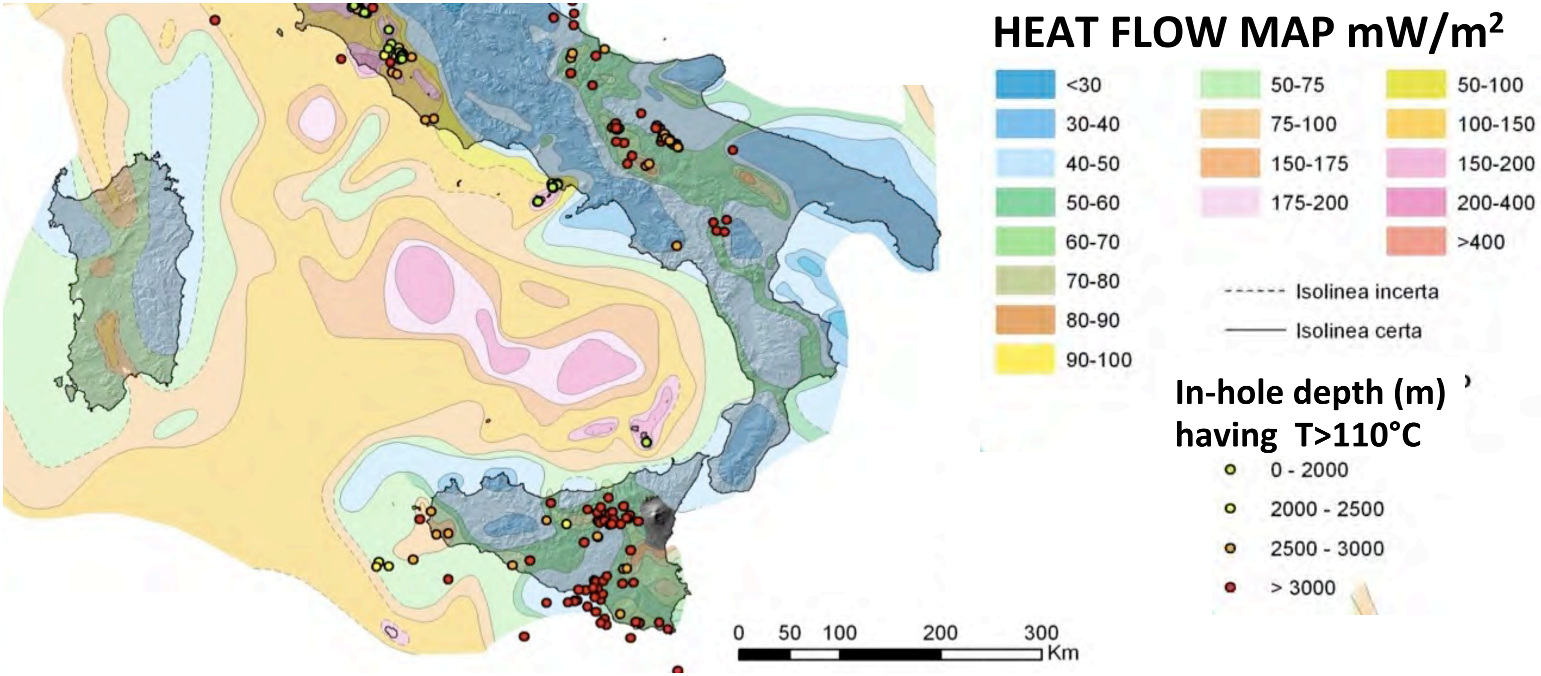
Realization of Data Centers

Evaluation of environmental issues and ways of reduction

Information, promotion and training

Power production

Common features



- Data collection and organization
- Extensive review of well temperature data, underground hydraulic conditions
- Thermal modelling of the underground, down to 10 km
- Thermal conductivity lab measurement
- 3D modelling of deep geological main structures
- Web mapping facilities

Different Products

- Local feasibility studies
- Technical and economical evaluation
- Regulatory aspects
- Regional geothermal potential maps
- Dissemination of VIGOR results and conventional uses of geothermal energy

Atlante

- Environmental aspects
- Regional maps of thermal springs, hydrothermal resources, temperature distribution at depth
- Regional favorability maps
- Dissemination and promotion of geothermal energy for power production, UGR and EGS

Geothermal Energy

TOWARD THE FUTURE

REQUIREMENTS

A comprehensive identification of resources and opportunities, as well as an accessible collection of data and information

A clear and easy to follow regulation for authorizations in the exploration, drilling and exploitation phases of the project

The promotion and dissemination of technology, values, economics

Research and technological development

Political challenges

to invest in data collection, providing the funding for an extensive exploration of the underground in areas where data are few and/or potential is high

to face the risk of the first exploratory well / insurance

Technical challenge

to create the systems and technologies that will streamline and optimize the sophisticated and complex workflow of a geothermal project

Technology & research efforts

Engineered Geothermal Systems (EGS) technology:
advancements in exploration, drilling, stimulation, management requires many research&demonstration projects

Unconventional Geothermal Systems (UGS) technology:
emerging activities to harness energy from nowadays non-economic reservoir would make significant progress with qualified input from research. in particular, reservoirs with ***supercritical fluids*** (fluids in the thermodynamic area above the critical temperature and pressure) and ***geopressurized reservoirs*** (deep sedimentary basins where fluids show high pressure and are rich of chemical elements or gases). This includes, beside peculiar power conversion and reservoir technology, also Operation & Maintenance techniques in aggressive geothermal environments, since they require specific solutions for corrosion and scaling problems. It will lead to an ***overall increase in power production***

Logistical and organizational challenge

to create the units and the processes within the geothermal community

And then …