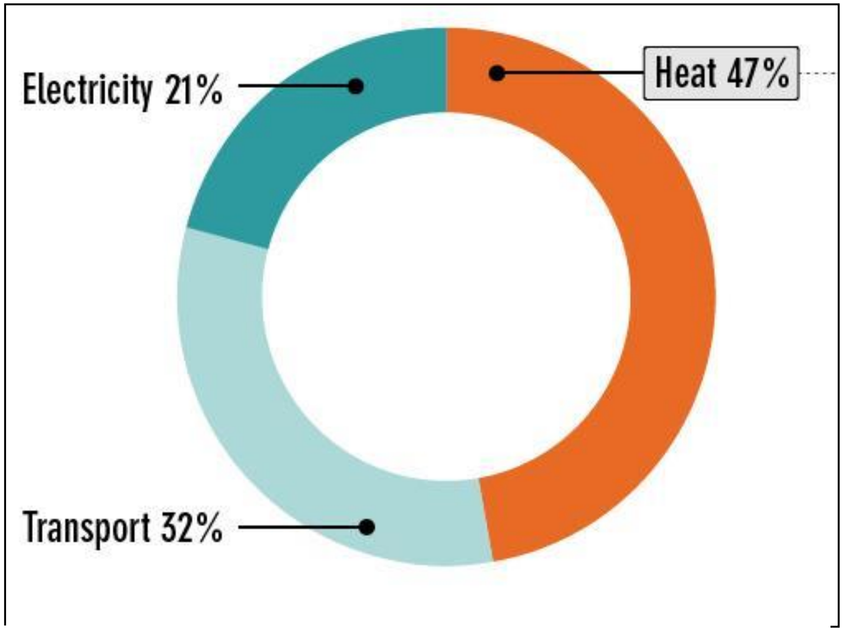
Refurbishing depleted O&G wells for geothermal

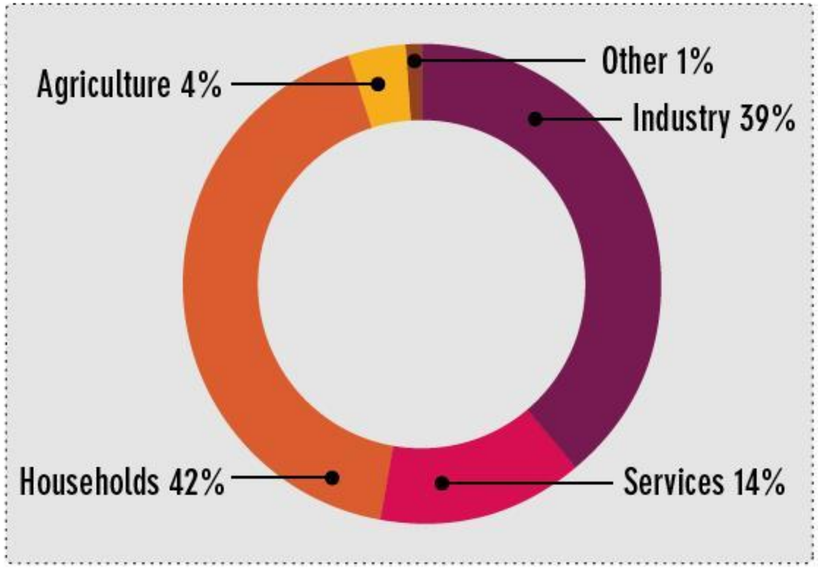
- **decarbonisation of the energy sector**
- **transformation and improvement of the energy-producing systems to meet the decarbonisation targets and a reduction of greenhouse gas emissions**

geothermal repurposing of depleted O&G wells could be an alternative to the mining closure

- geothermal energy promising due to its **wide range of applications depending on the temperature of extracted fluids**

Primary energy consumption * in EU27





da RHC Platform, SRIA 2013, dati 2010

- ✓ 47% (about 544.2 Mteo) is due to the production of HEAT (percentage in line with other industrialized countries)
- ✓ **HEAT understood as the consumption of thermal energy for the production and use of heat in stationary applications**

of which 42% is related to the air conditioning of buildings sector with high potential to reduce the total consumption of EP in the EU and to decarbonize the entire energy system

(*) primary energy EP = energy power of a naturally present resource that is used to directly produce electricity, for example: oil, coal, gas, etc = Chemical energy from fossil fuel).

preliminary investigation of oil and gas fields located onshore in Italian territory based on the available information on temperature distribution at different depths

- ✓ **O&G production** in its mature stage is often associated with a large volume of formation waters
- ✓ **increasing the maturity of hydrocarbon fields** increases water production as well
- ✓ **when the hydrocarbons wells are going to be depleted**, they can be converted into geothermal wells

The selection of the final use (production of thermal power or electricity) and the potential of geothermal production depend on the temperature, pressure, and flow rate of water, which are functions of the local geothermal gradient, well-depth, and poro-perm properties of the reservoir rocks

modificato da Soldo et al 2020

key points for the geothermal sector

- **to reduce uncertainties on profitability**
- **to design sustainable solutions for large-scale development out of the conventional assets**

modificato da Soldo et al 2020

Advantages of reuse of abandoned wells

- **no/limited emission of CO_2 into the atmosphere during wells repurposing**

- **the local communities can produce a renewable energy source from existing infrastructures**

- **the companies can reduce well abandonment costs**

modificato da Soldo et al 2020

Repurposing wells for geothermal transform wells from liabilities into assets

Electrical generation potential (T > 120 °C)	**power generation wells** **within 10 km of transmission lines**
Industrial heat (T > 90 °C)	**industrial heat wells** **within 10 km of road networks**
Direct heat potential (T > 60 °C)	**DH wells** **within 10 km of road networks**

modificato da Chapman 2020

Law and Policy Approaches and Recommendations

1. **development of a provincial/regional geothermal statute and/or regulations**

2. **modification of current O&G law** (i.e. offer inactive wells for geothermal purposes)

3. **development of a more favourable tax regime** (i.e. allowance for companies involved in repurposing abandoned wells for geothermal)

4. **creation of specific authorities devoted to repurposing abandoned geothermal wells**

modificato da Chapman 2020

method to extract GE from abandoned gas wells

- **dual well system** (at least **one injection well** and **one production well**)

- **deep closed loop system**
  - **multiple horizontal wells (Eavor system)**
  - **coaxial solution (deep borehole heat exchangers)**
  - **double-pipe heat exchanger**
  - **u-tube heat exchanger**
  - **wellBore Heat eXchanger (WBHX)**

pro

- no geothermal fluids production
- environmental impact and energy for reinjection strongly reduced
- corrosion and scaling problems avoided

cons

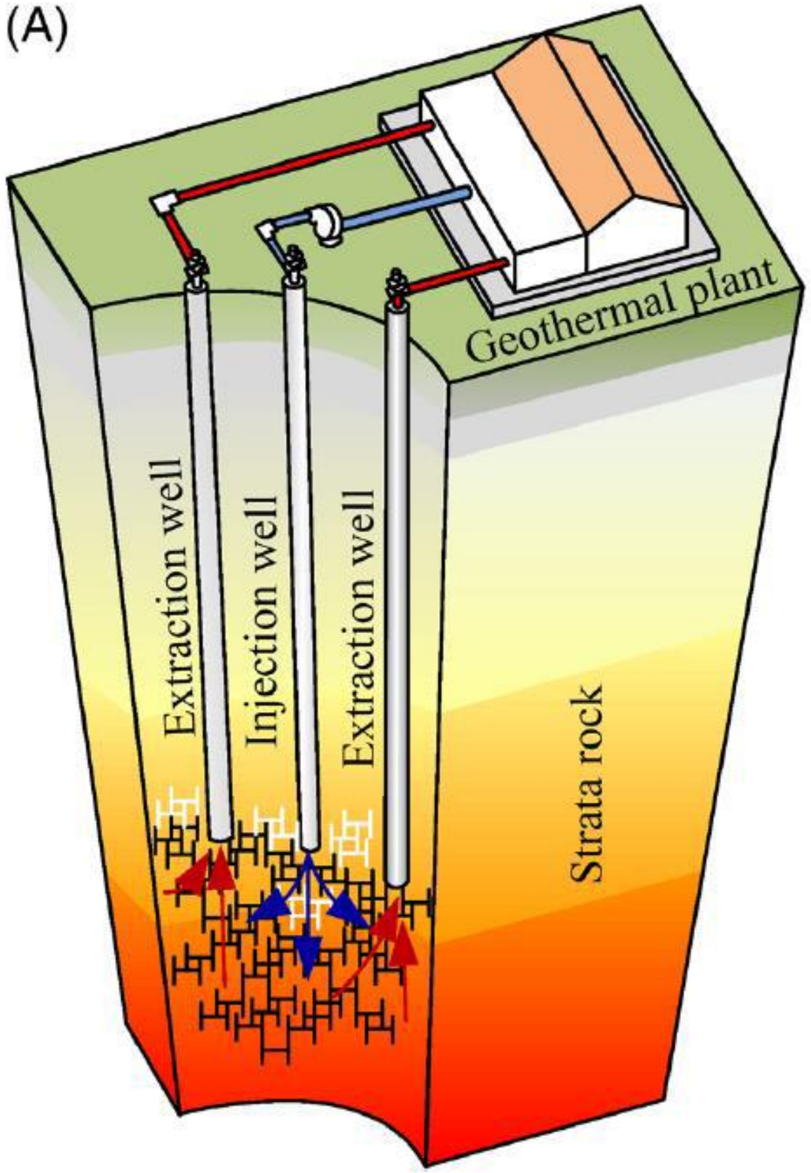
- reduction of the heat recovery efficiency

- **exceptional enhanced geothermal reservoirs**
  - **extraction of energy by oxidizing the residual oil with injected air**

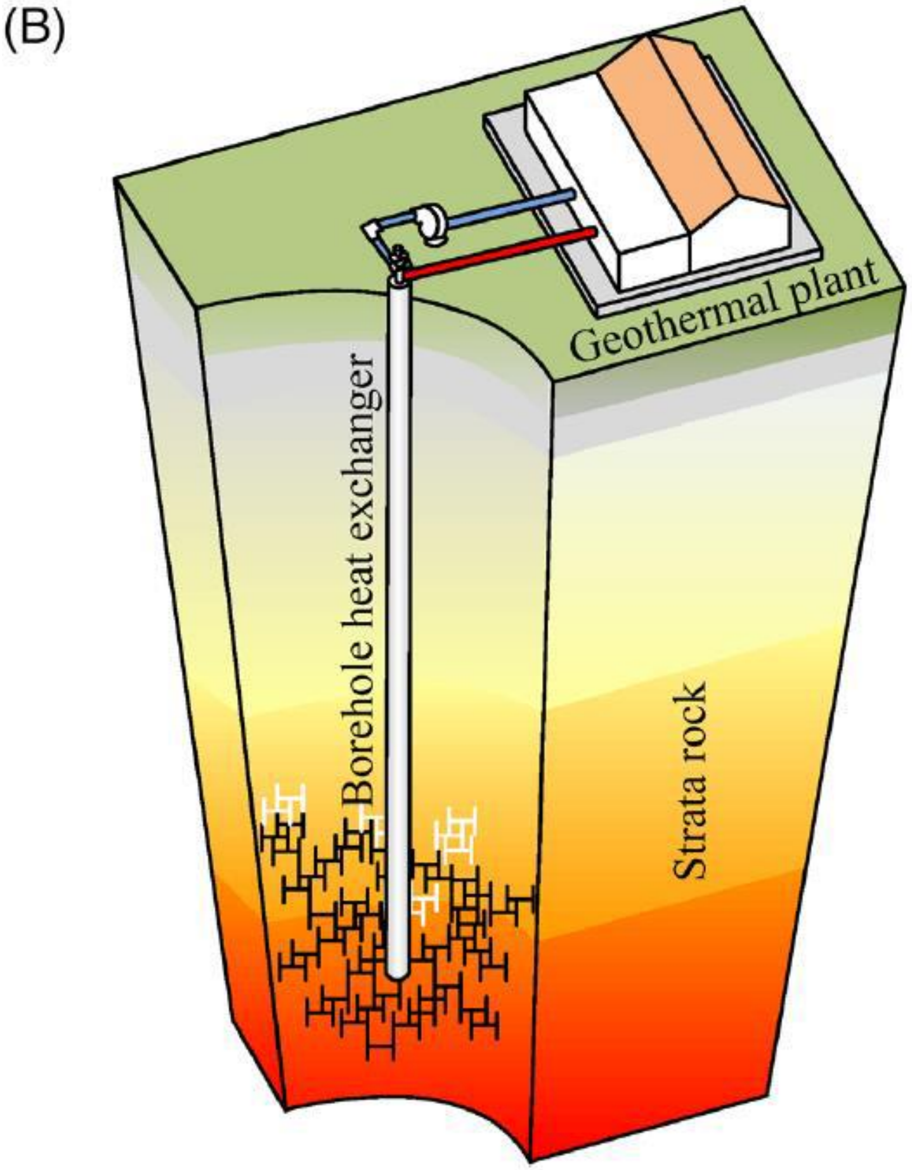
modificato da Mehmood et al 2019

Deep geothermal solutions for retrofitting ex O&G wells

A. Open loop geothermal plant

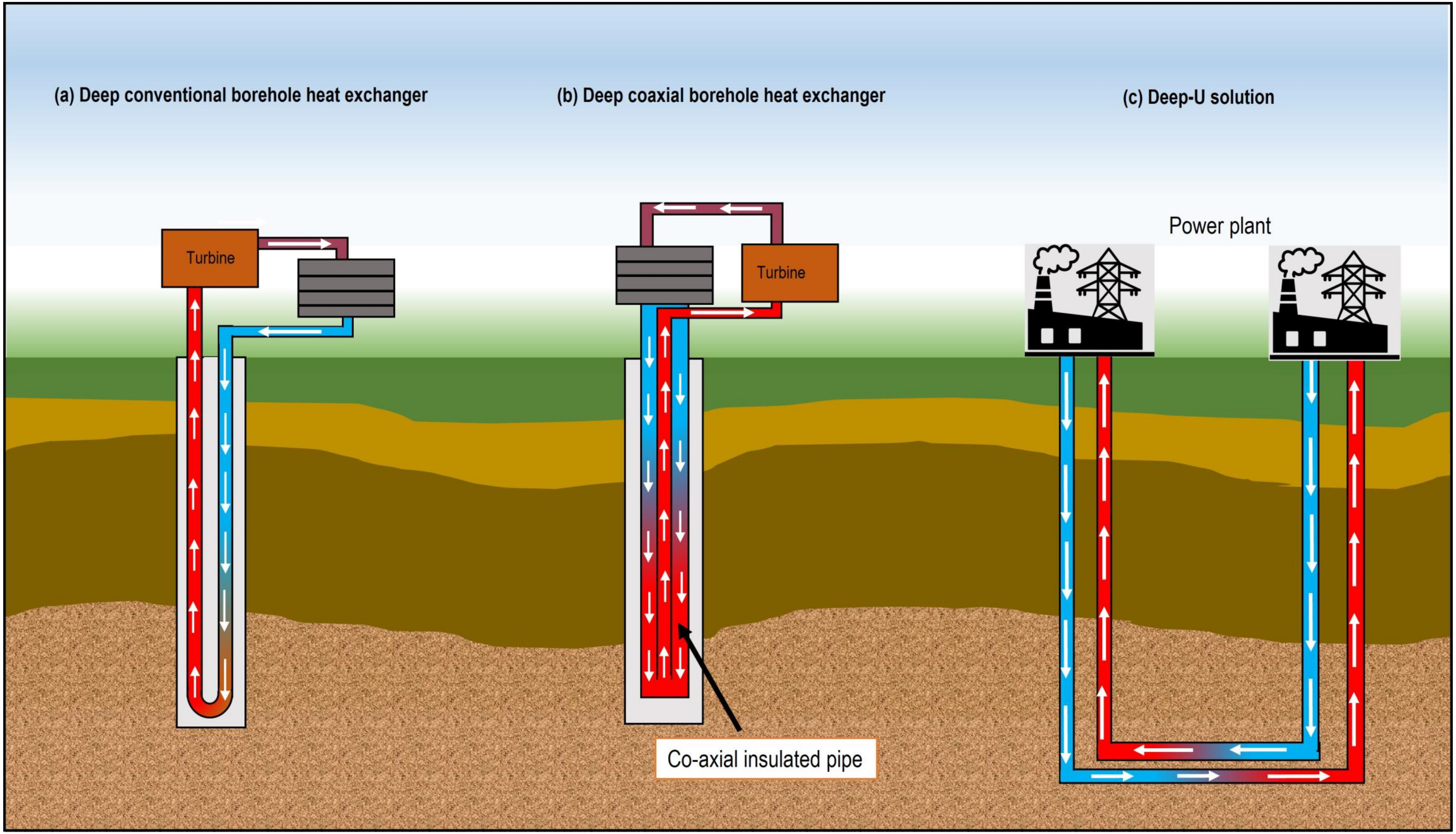


B. Closed-loop geothermal plant

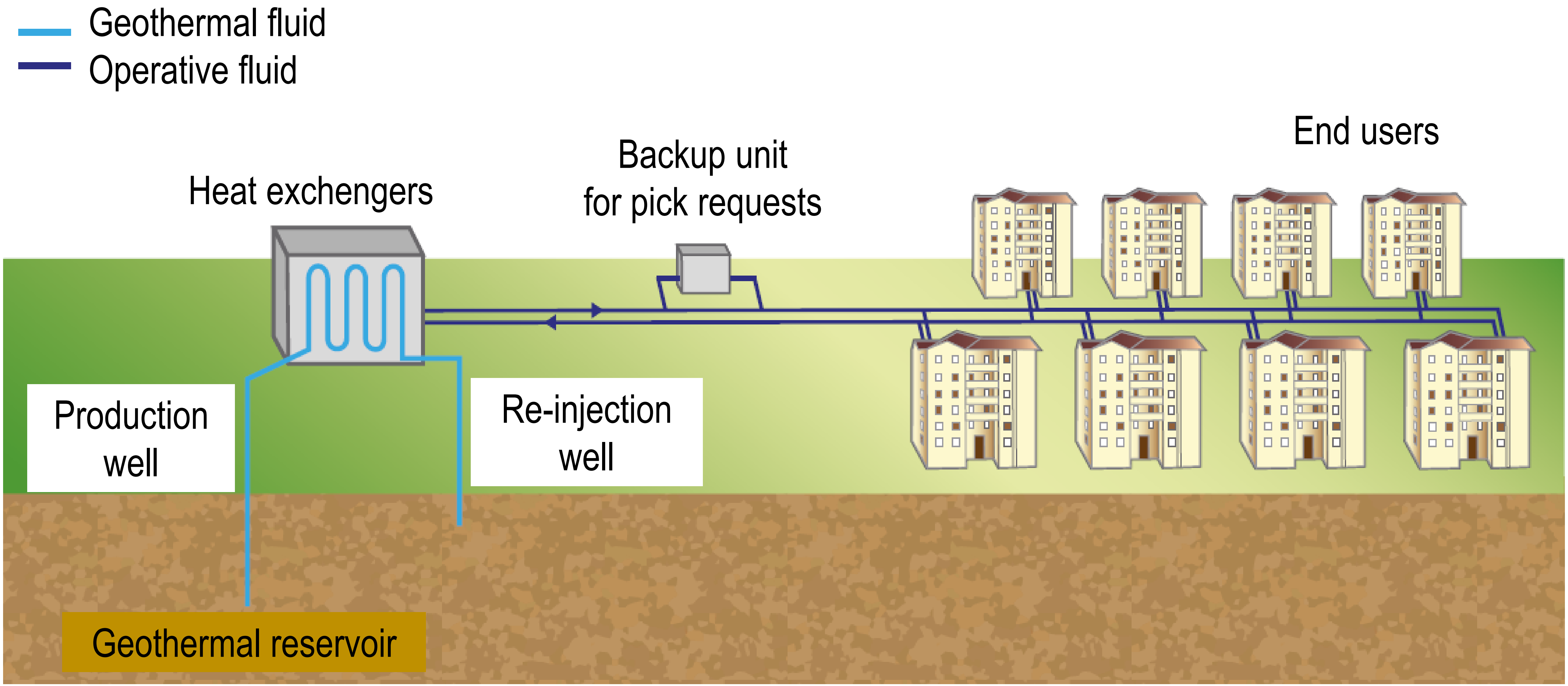


Modified from Kurnia et al 2021

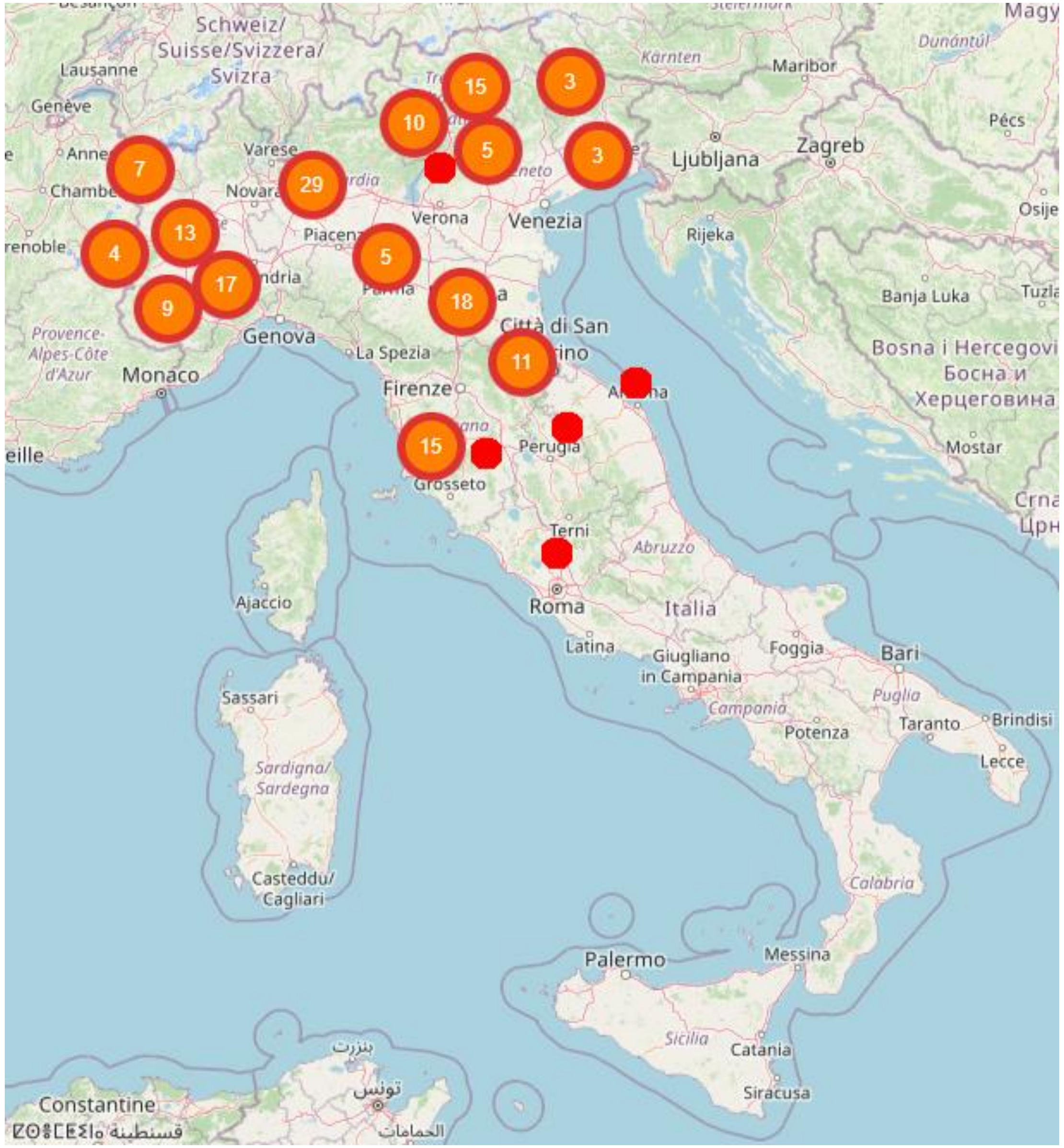
Comparison between different geothermal deep closed solutions



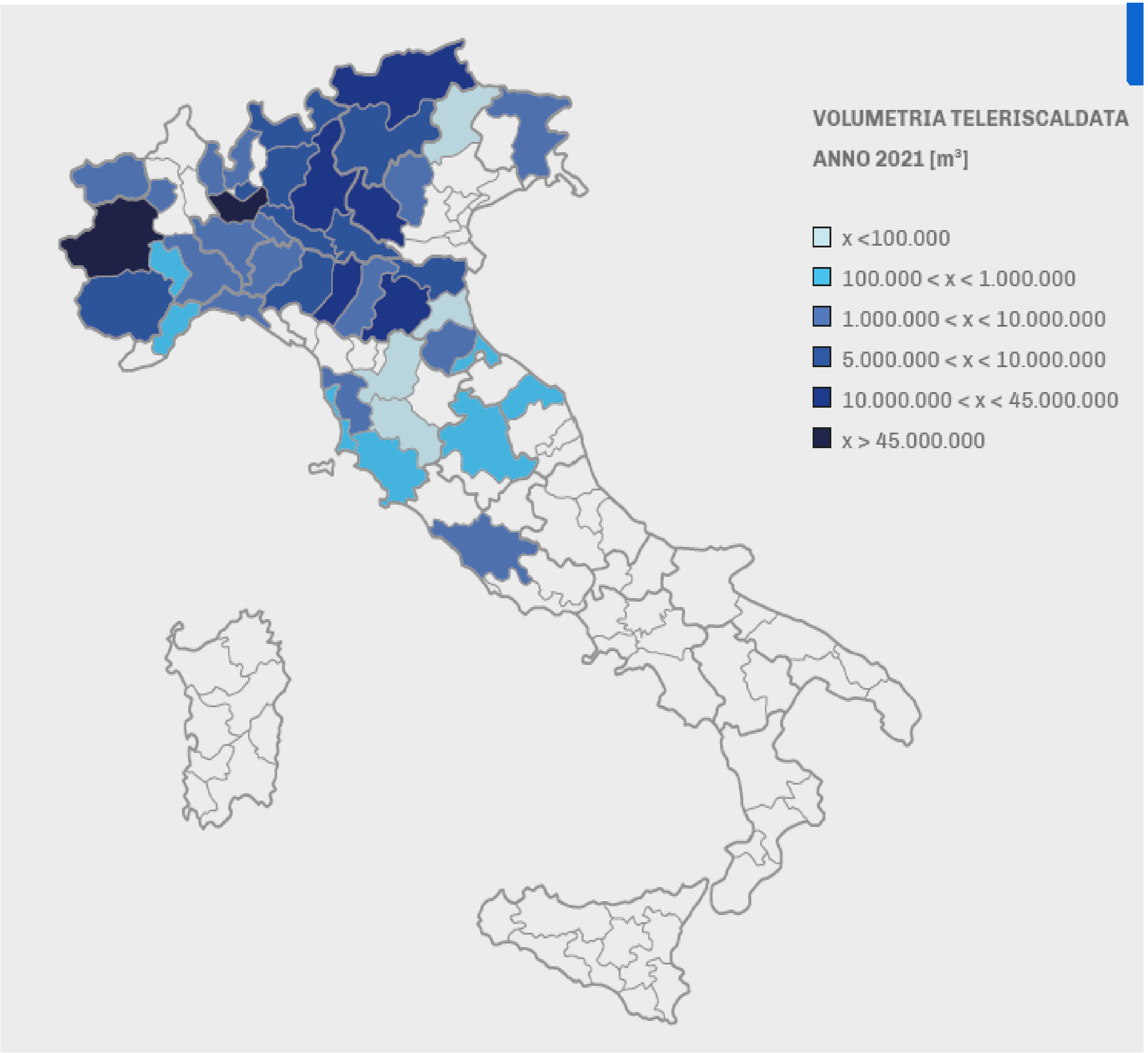
District heating



Map of district heating systems monitored in Italy



Volume heated by district heating in 2021



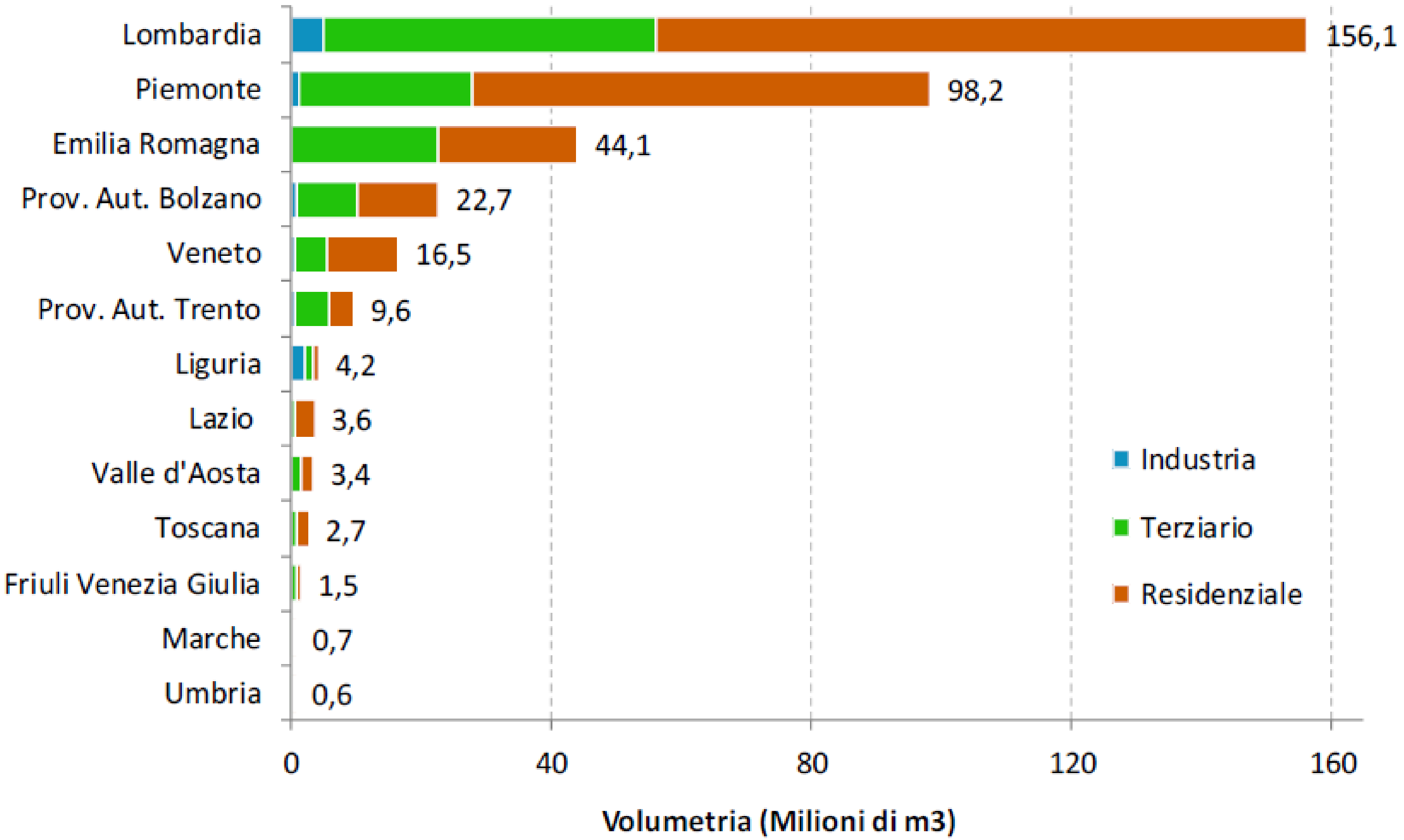
Source: AIRU – Associazione Italiana Riscaldamento Urbano

Heated volumetrics by sector in 2018

→ **Residential users represent 63%** *(of the total volume heated in Italy by district heating networks)*

→ **Tertiary sector (35%)**

→ **Industrial users (3%)**



About 43% of the total heated volume is concentrated in the territory of Lombardy (156 million m3); followed by Piedmont (98 million m3, 27% of the total), Emilia Romagna (44 million m3, 12% of the total) and the provincial territory of Bolzano (23 million m3, 6% of the total).

Source: GSE Report – May 2020

Electricity generation from geothermal sources

1) **High enthalpy (geothermal source at T>160°C)**
<u>GEOTHERMAL FLUID AS OPERATING FLUID</u>

→ Dry steam power plant (a)
→ Single flash steam power plant (b)
→ Double flash power plant (d)

2) Middle and low enthalpy (geothermal source at 80<T<180°C)

<u>GEOTHERMAL FLUID AS A HEAT SOURCE for the ORC cycle</u>

→ Binary cycle power plant (c)

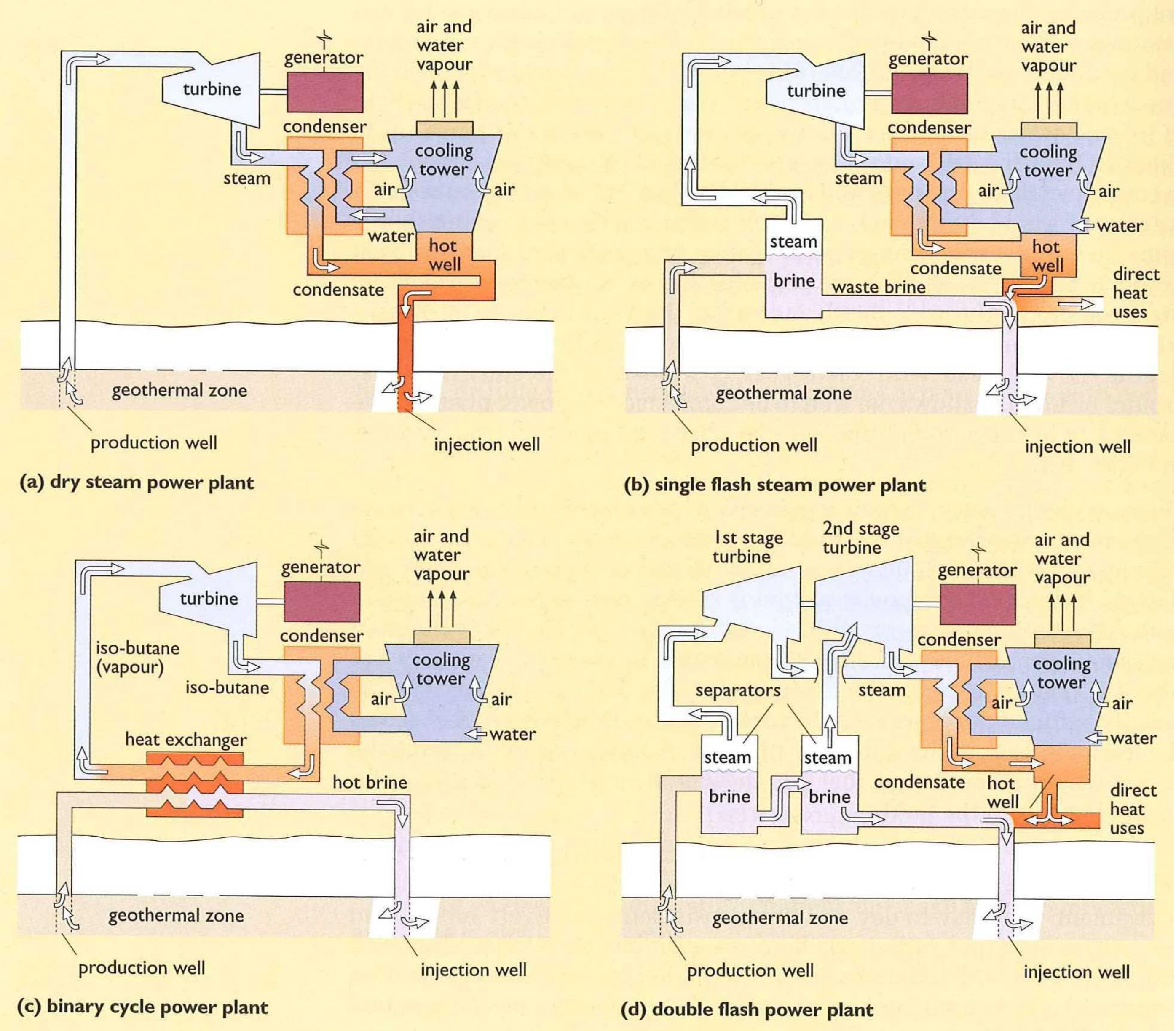


Figure 9: Types of above-ground installations for the generation of electricity from geothermal sources. (Course notes Renewable Energies-dip. Industrial Engineering Unipd)

Inactive and abandoned wells in Italy from 1940 to 2005

Database ViDEPI

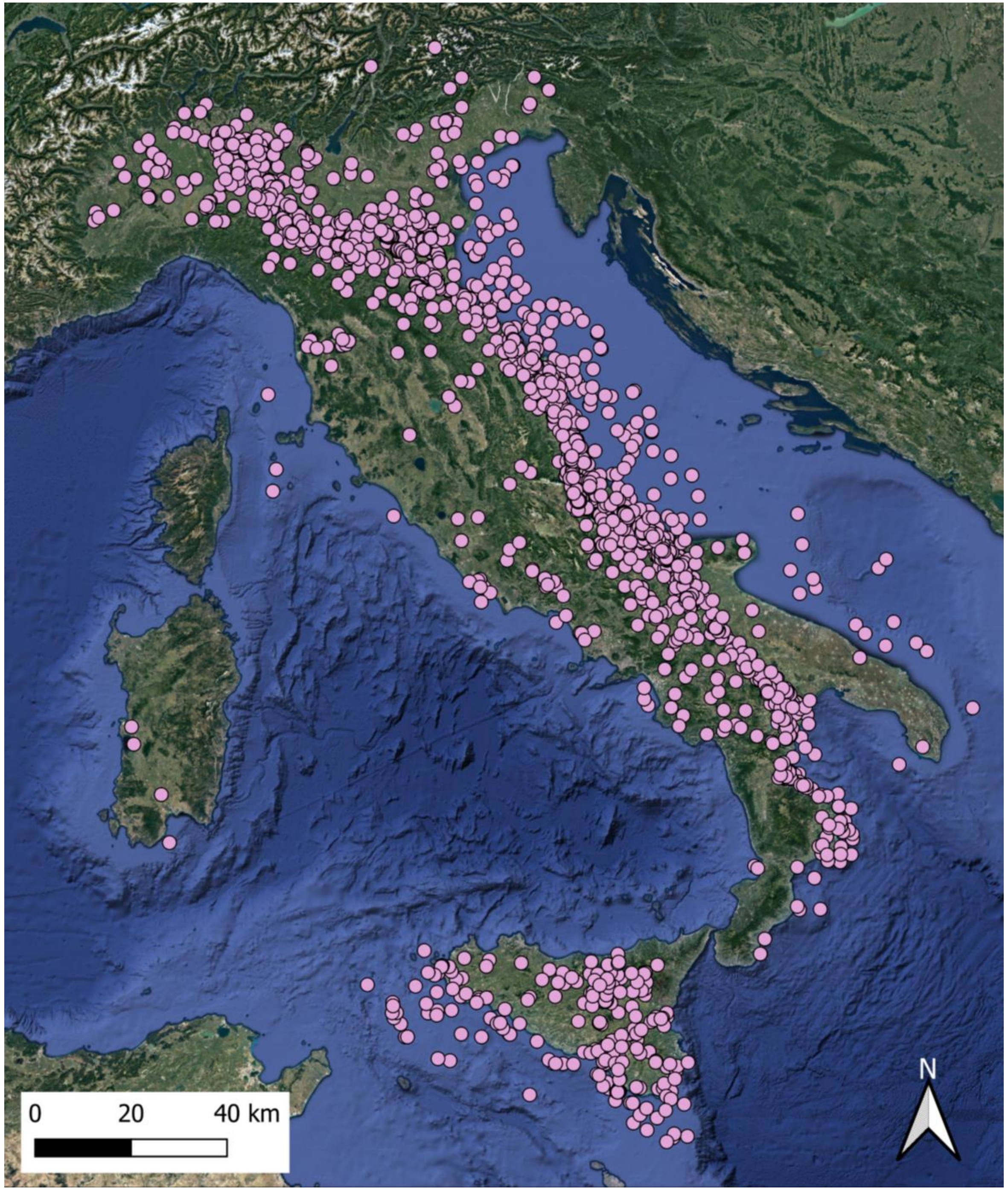
(QGIS visualization software)

→ Onshore wells (around 4500 wells)

→800 m > Depth > 7000 m

→Thermal anomaly area, normal and low gradient area

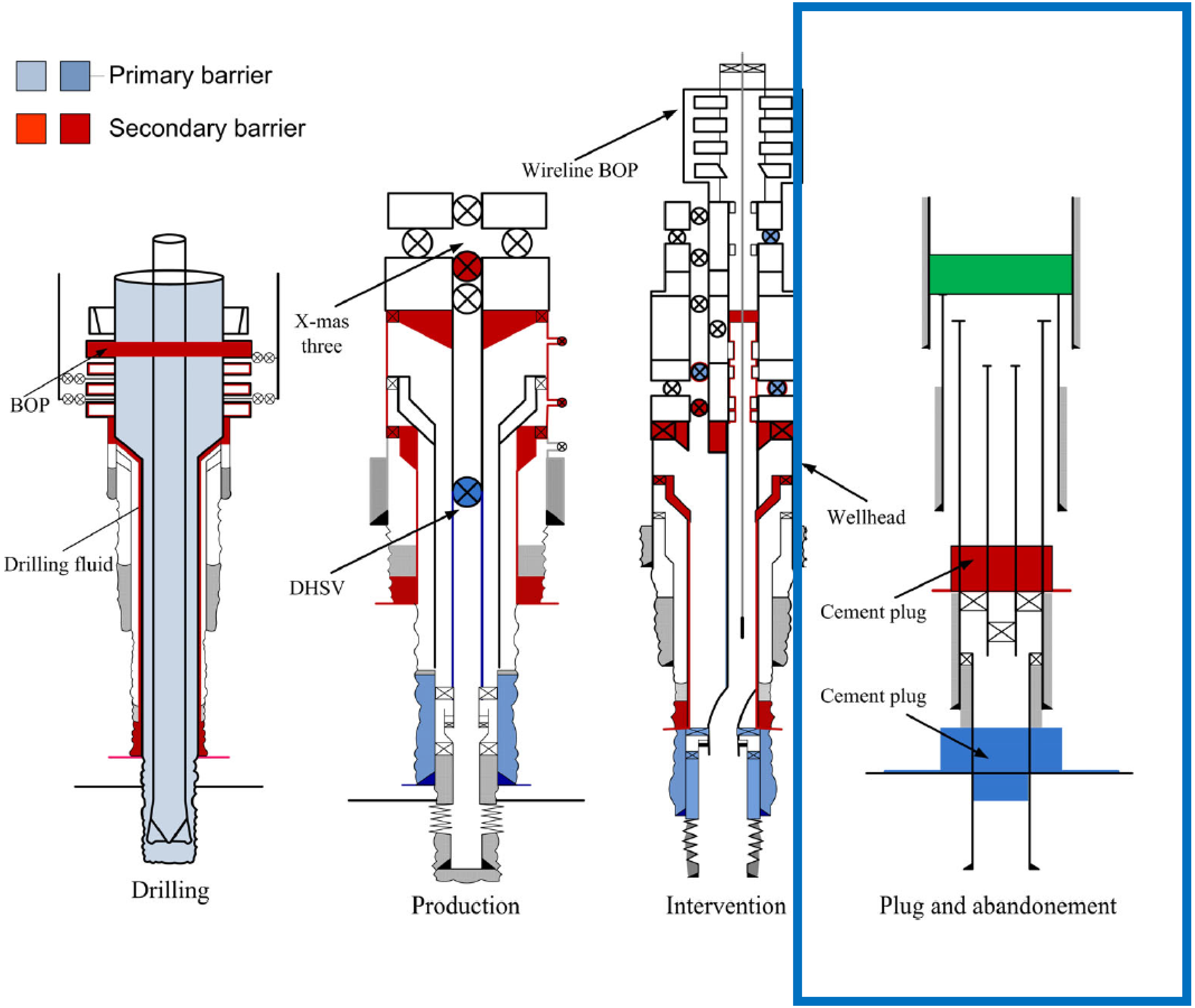
→Nearness of possibly users for heat and power supply



Project stage	Spending
Exploration-Feasibility	13%
Exploration-Drilling	6%
Drilling	44%
Field Gathering System	8%
Plant Construction and Startup	30%
Total	100%

Modified from Kurnia et al 2021

Overall costs of a geothermal project



Decommissioning and abandonment of a well

- Seal of all the lithological strata crossed by the well

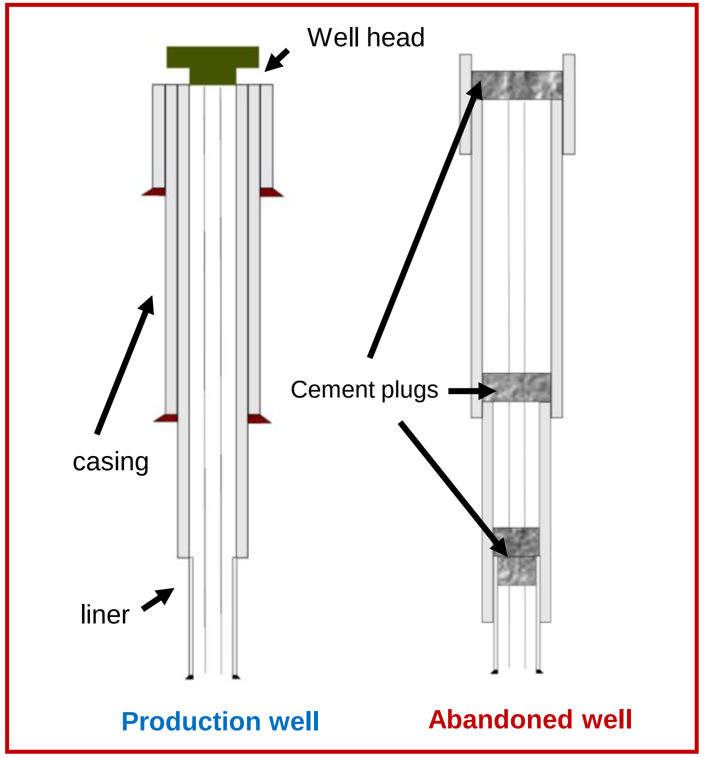
Important to know the type of cement plug installed to evaluate all interventions for the retrofitting

Modified from Kurnia et al 2021

Selection criteria for case study and sample analysis

Geo	Status of the well	End users and DHC	Energy request
BHT (°C)	Open/closed	Distance	Heat
Geothermal gradient	Well head?	Cities	Electricity
Lithology	Cement plugs		ISTAT data

BHT (°C)	
< 90°C	Low
90°C < BHT < 110°C	Medium
> 110°C	High



Volume served by district heating, fuel used to feed the plants, ownership and management of the networks in provincial capitals/metropolitan cities - Year 2021 (absolute values in m3)

EXAMPLE:

CITY:	Serving volume (m^3)	Fuel used					
		Natural gas/ methane	Municipal solid waste	Biomasse	Carbon	Geothermal energy	Other
Milano	34.533.637	X	X	-	-	X	-
Monza	4.696.024	X	-	-	-	-	-
Bergamo	7.730.332	X	X	-	-	-	-
Brescia	40.915.549	X	X	X	-	-	X

Advantages on retrofitting O&G wells

- Drilling activity is strongly reduced → the wells already exist
- a lot of data are available (data logs)→ collected during the exploration and perforation activities
- complete well performance estimation → minimizing risk and providing a better cost estimations
- conversion of existing facilities in the oil wells to support the production of geothermal energy → saving a considerable cost as compared to constructing a new geothermal energy drill hole and plant
- decommissioning cost of old well minimized or even eliminated → well economic life extended and potential problem with liquid/gas leakage of sealed wells minimized

Lack of policy and regulations on the utilization of abandoned oil and gas wells as geothermal wells

The environmental effect on retrofitting abandoned oil well has not been deeply investigated yet

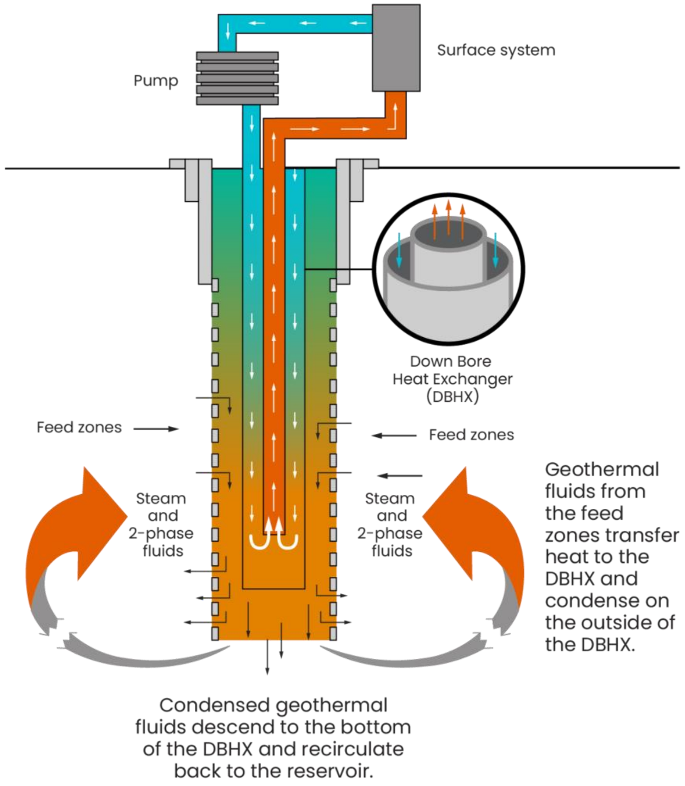
The heat loss during the transport from the well to the end-users

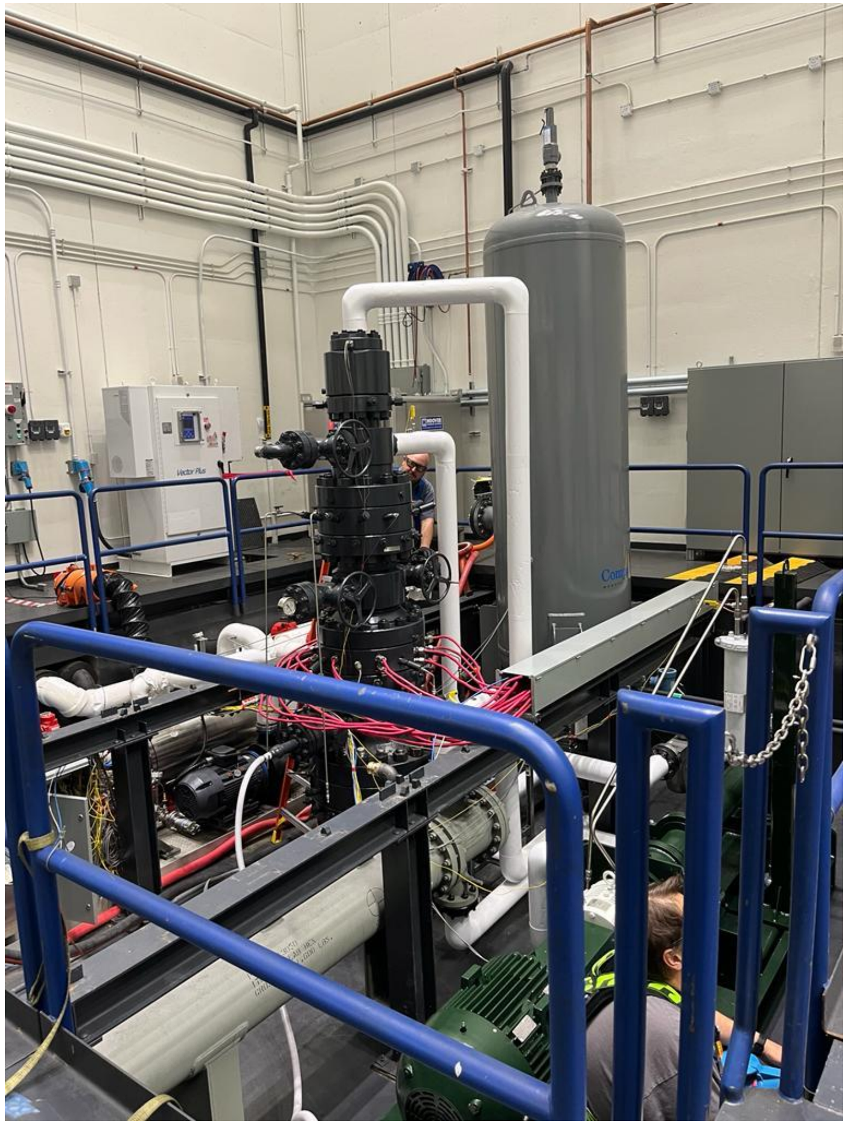
Barriers

GreenFire solution – Baker Hughes GreenLoop

GreenFire Energy

- Well retrofit
- Coaxial BHE
- Closed loop





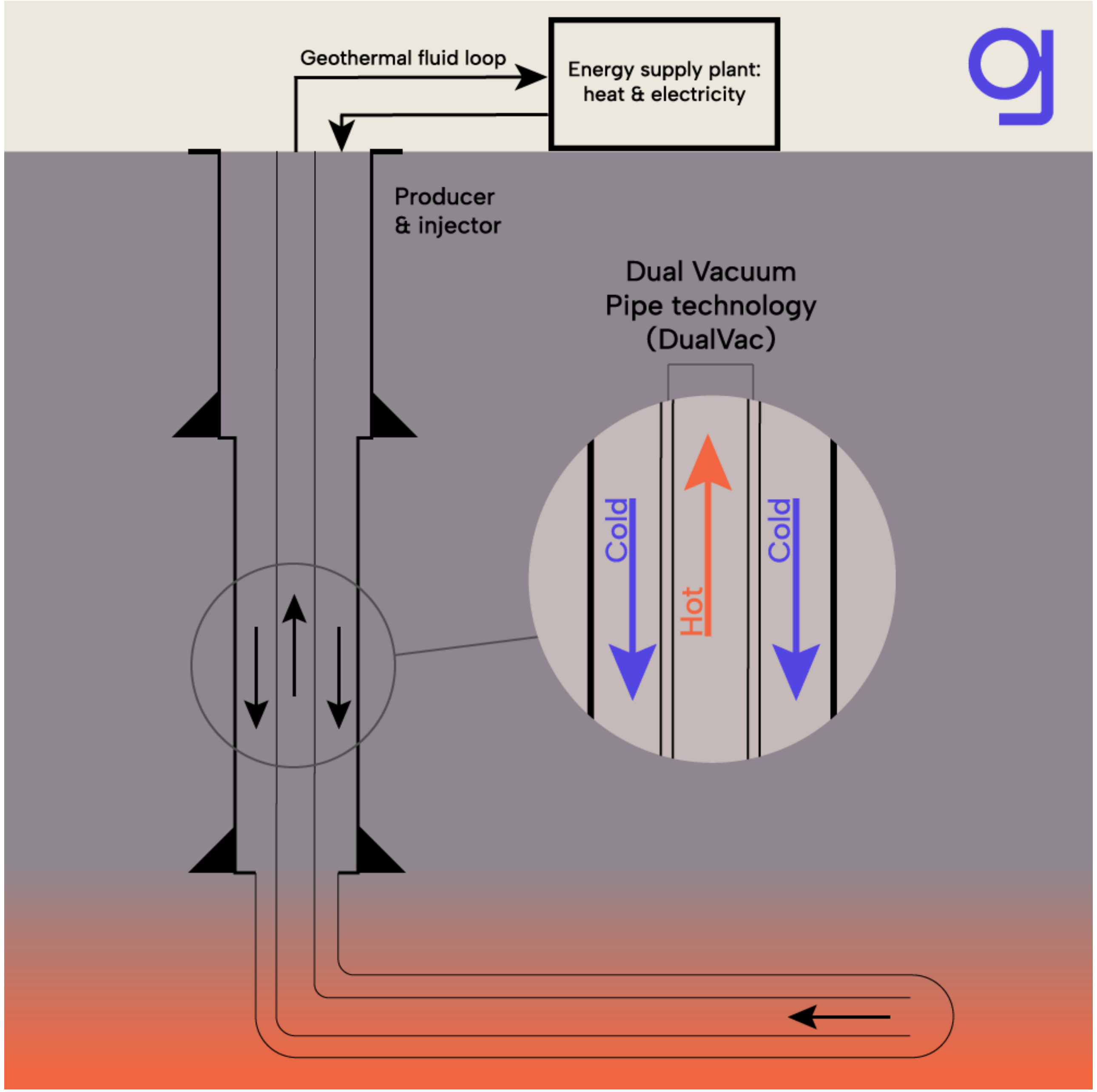
Wells2Watts pilot site (Oklahoma City)

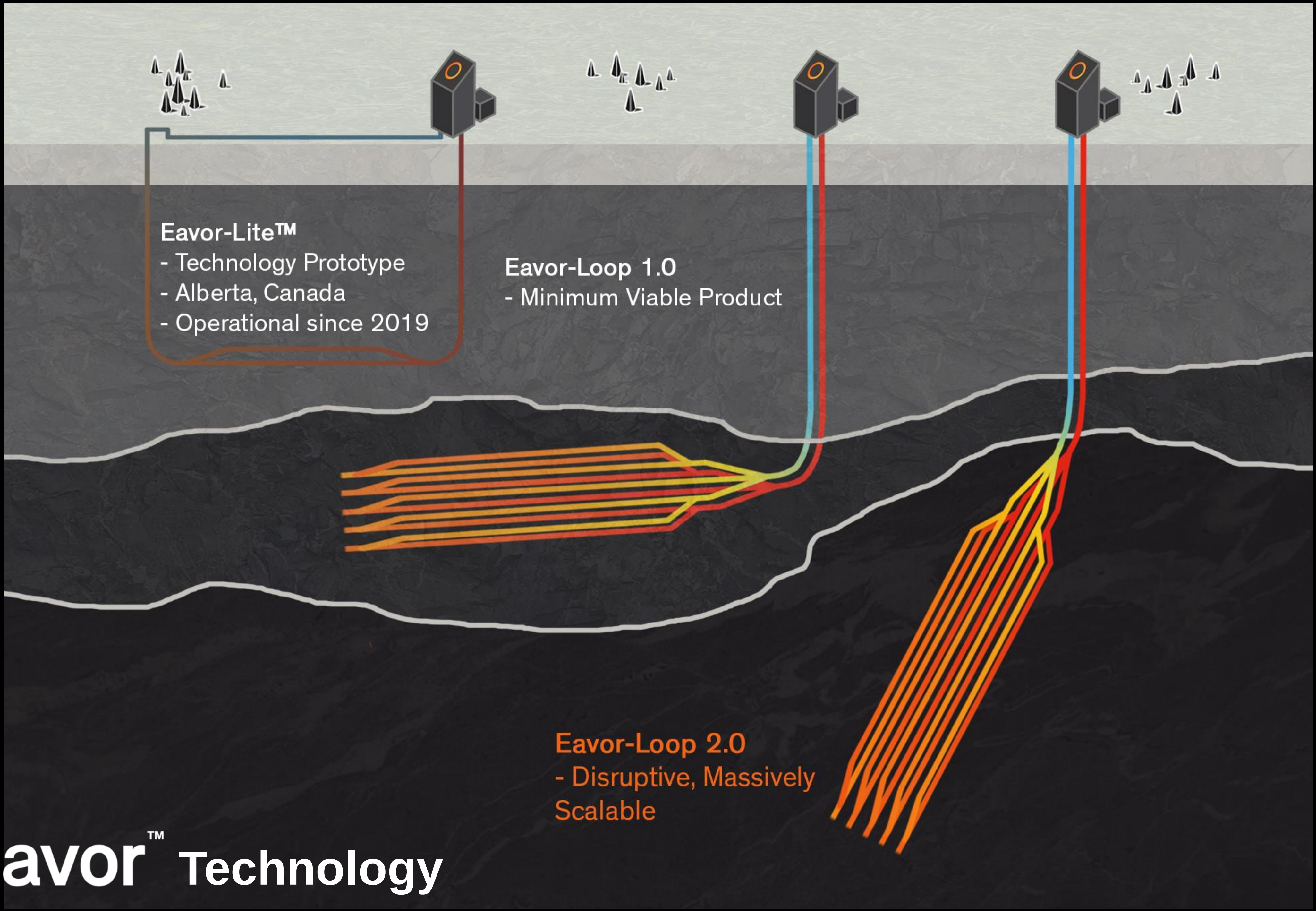
green therma

GreenTherma solution
Heat4Ever

- No liquid into formation
- No need for aquifers
- No pollution of the subsurface or in the drinking water
- No risk of formation damage or induced seismicity
- No need for fracking of formation

Dual Vac technology





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Energy Conversion and Management: X

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Sustainable reuse of oil and gas wells for geothermal energy production: Numerical analysis of deep closed loop solutions in Italy

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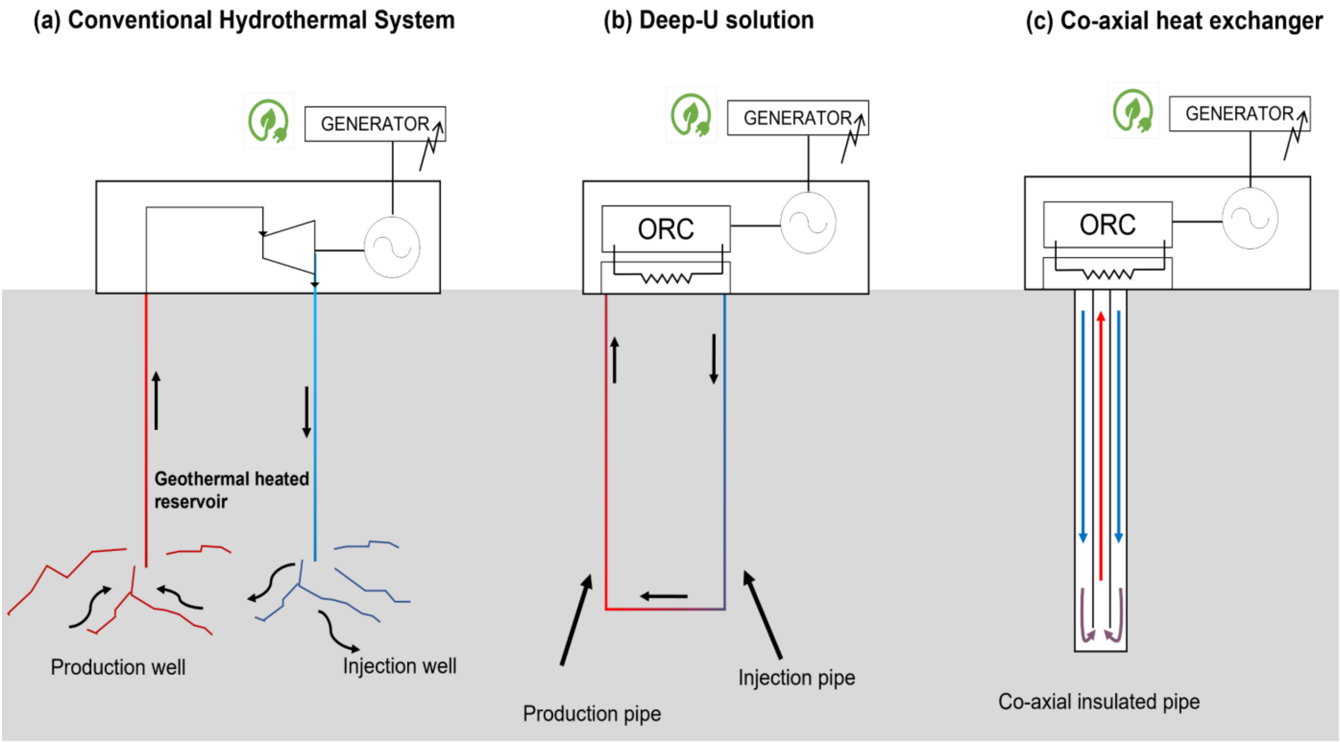
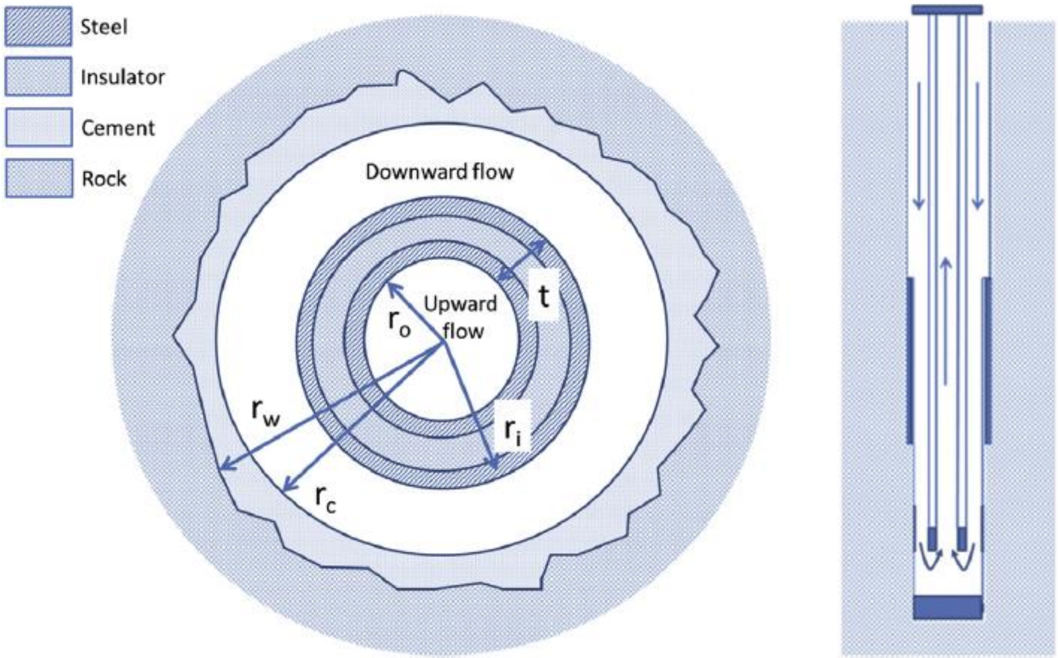


Energy conversion by an ORC Plant

Wellbore heat exchanger (WBHX): cross section and schematic layout

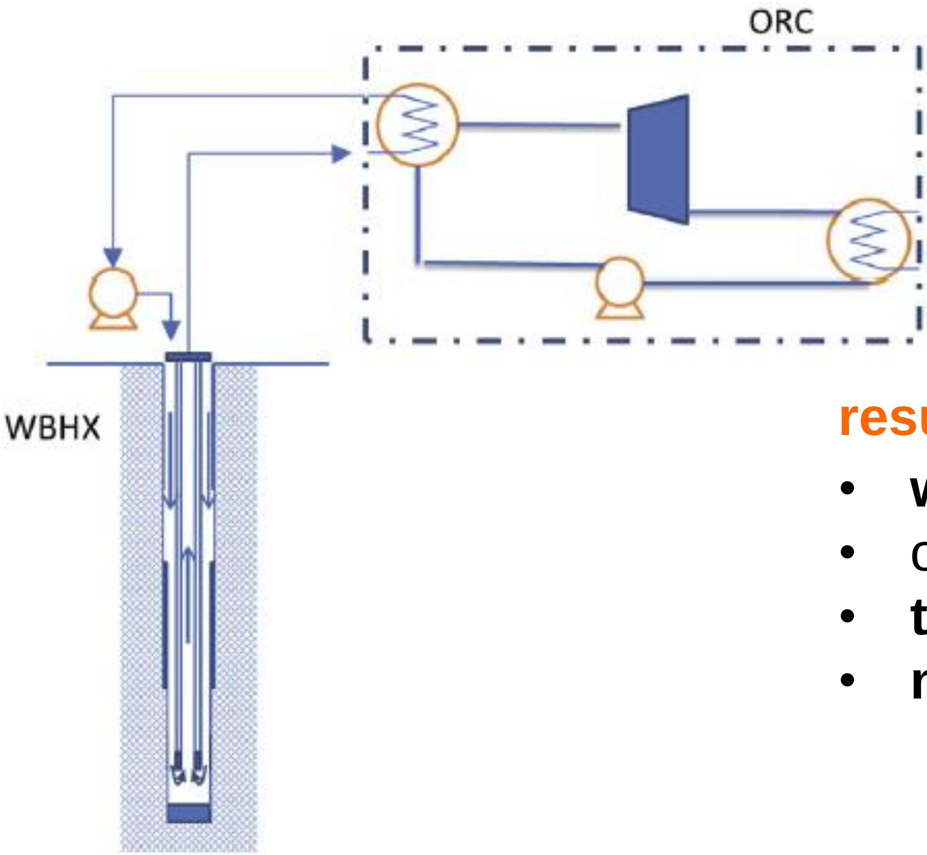


- ✓ **well bottom closed**
- ✓ **dual shell coaxial tube** inserted into the well
- ✓ heat carrier fluid enters the WBHX **in the annular space**
- ✓ **downward flow →** the fluid acquires heat from the surrounding ground
- ✓ **upward flow →** the fluid is diverted and flows into the internal pipe up to wellhead
- ✓ **insulating material** in the gap between the two pipes

modificato da Alimonti et al 2016

Energy conversion by an ORC Plant

WBHX and Organic Ranking Cycle (ORC) system scheme



Trecate Oilfield

- depth 5.8 – 6.1 km
- T 160-170 °C

results for single well:

- **water** as the **best heat transfer fluid**
- optimum **water flowrate** of **15 m^3/h**
- **thermal power 1.5 MW**
- **net electrical power 134 kW**

electrical power < that of conventional geothermal power plants
thermal power used in district heating plant

modificato da Alimonti et al 2016

GE production utilizing abandoned oil and gas wells

- **Three different source temperatures (142, 157, 177 °C)**
- **depth 3km**
- **12 inch double-pipe heat exchanger**

could extract sufficient energy to drive a 3.2 MW turbine generator system

Fluid temperature/(°C)	Power, binary/kw	Efficiency, binary/%	Power, binary-flashing/kw	Efficiency, binary-flashing/%
90	432	5.7	546	5.8
100	624	6.7	780	6.9
110	852	7.6	1056	7.8
120	1116	8.6	1374	8.7
130	1416	9.4	1722	9.6
140	1752	10.0	2118	10.3

Powers produced from 60 kg/s of geothermal fluid by a simple binary cycle and a binary-flashing cycle based on data from Edrisi et al 2013

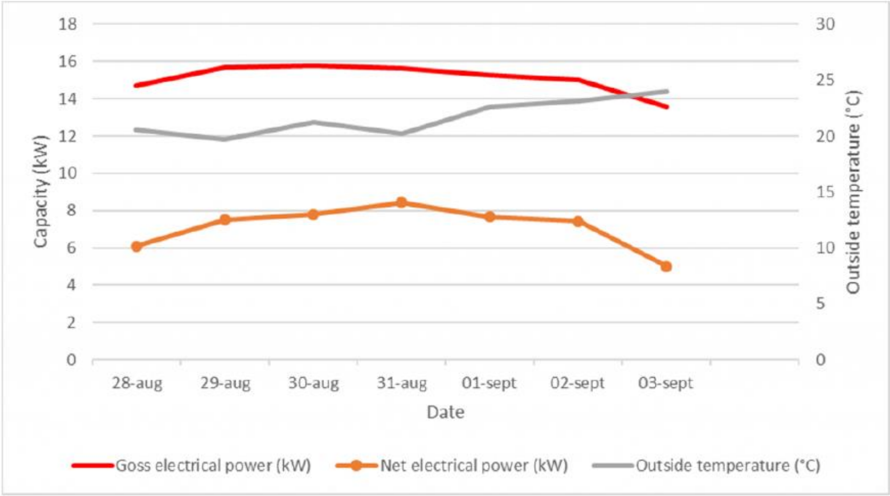
modificato da Mehmood et al 2017

MEET PROJECT (e.g. Vermillon, France)

developing a mobile small scale ORC able to produce electricity from 70-90 °C T range, which can easily be connected to an existing well.

- **300 wells in onshore oil fields**
- **40 of them with fluid flow > 10 m^3/h and surface T > 70°C**

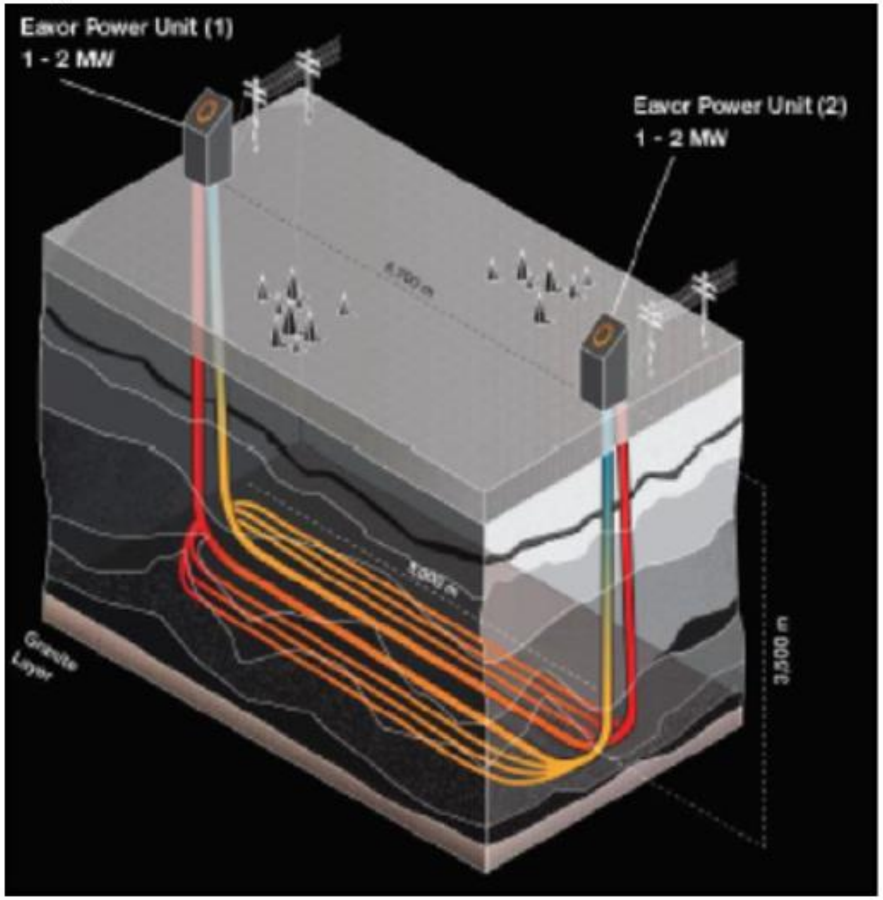
Enogia's ORC module installed in Chaunoy oil field (Vermilion's site), Paris basin (France)

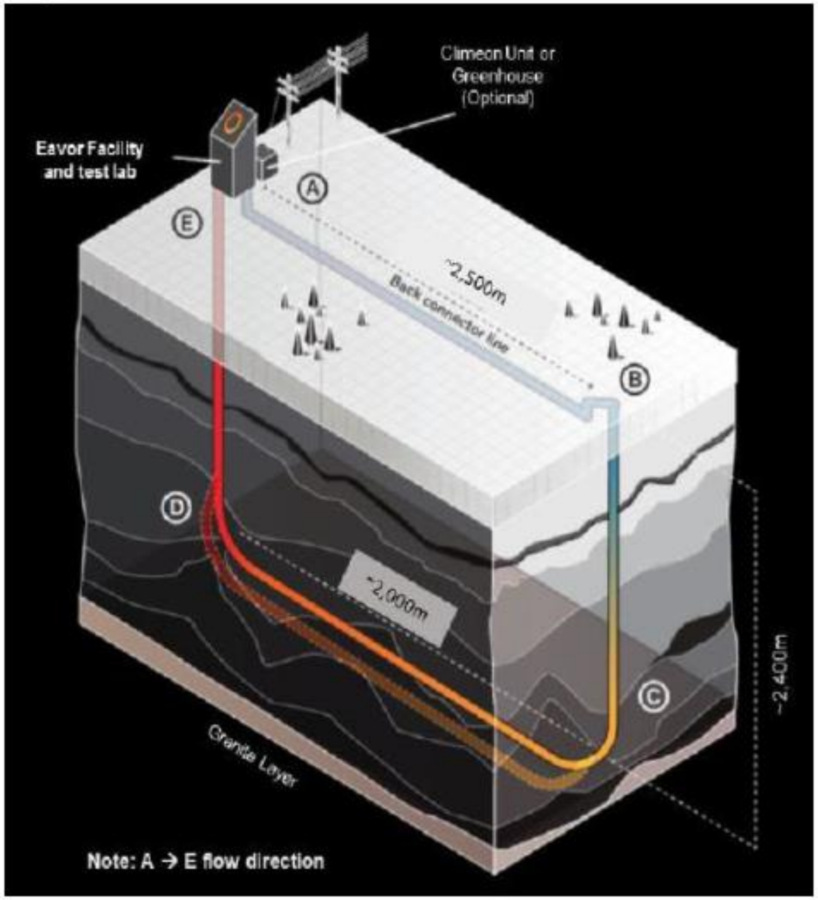


Power turbine result for a full week early September: gross daily average power output (red dots), net daily average poweroutput (grey dots) and average outside temperature (orange dots)

modificato da Dalmas et al 2019, ThnikGeoEnergy 12.10.2020

Closed-loop U-shaped heat exchanger systems (e.g. Eavor Loop, Alberta, Canada)



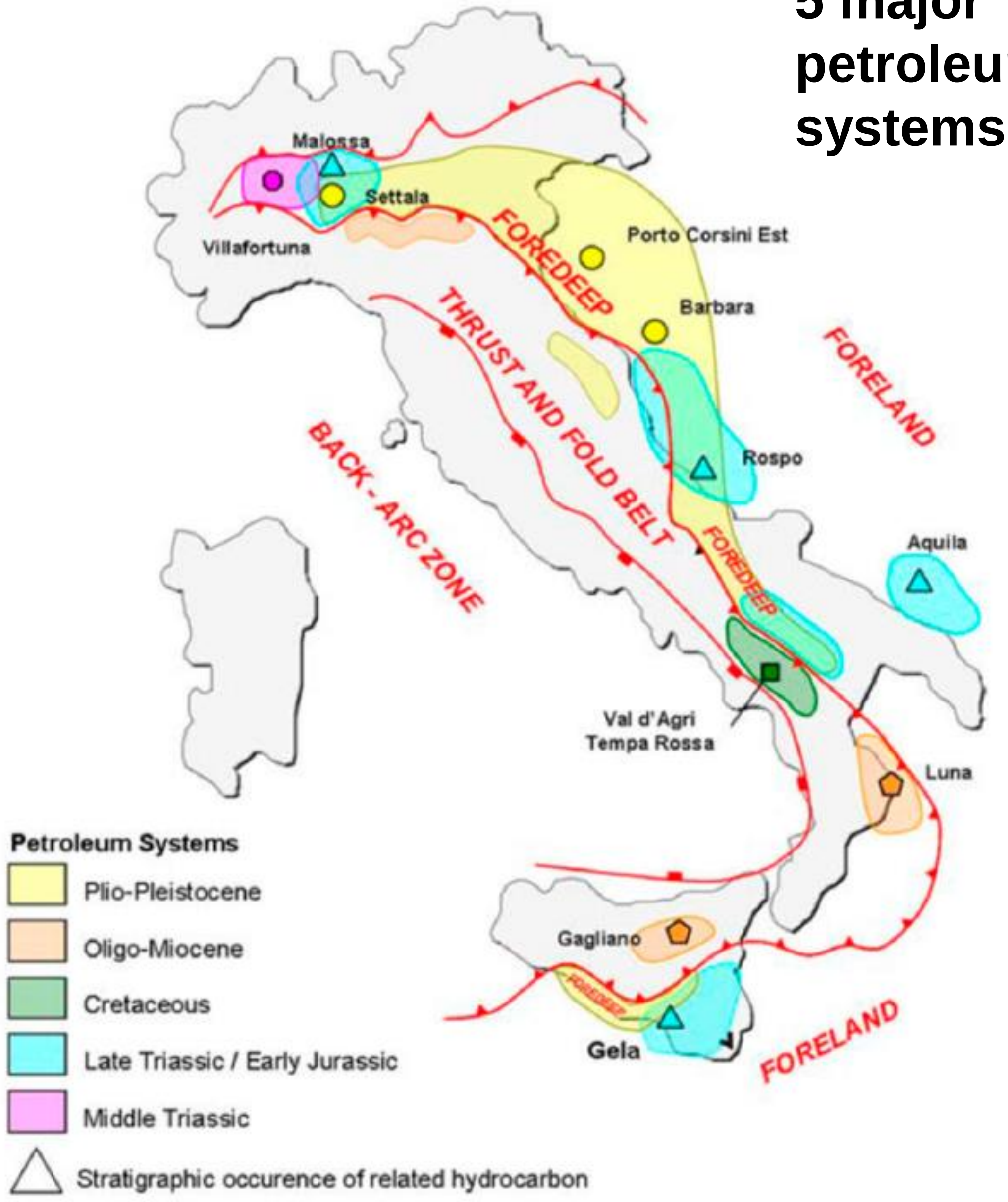


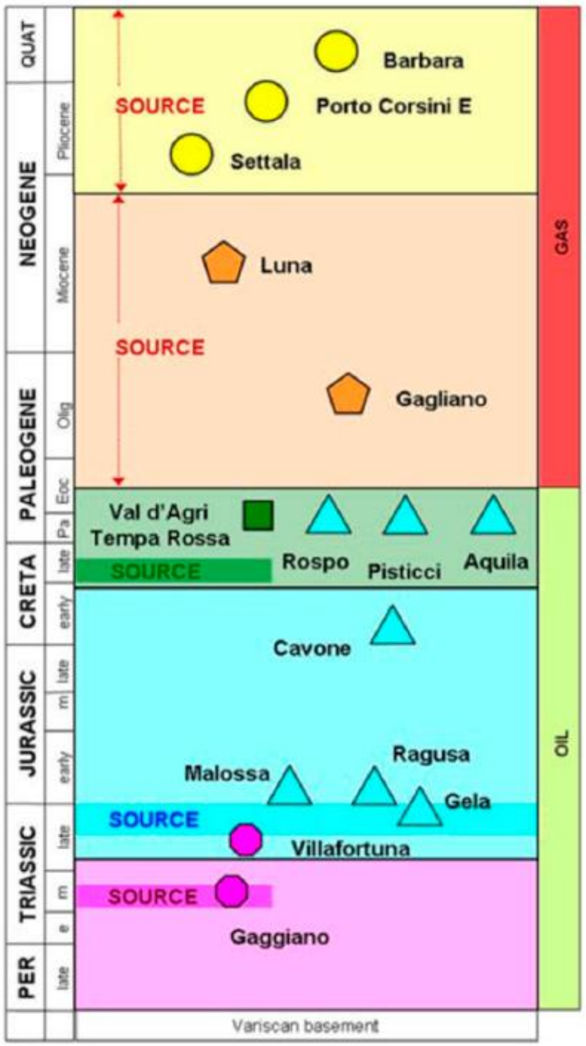
- **large U-tube shaped well with 2 multilateral legs at 2.4km depth**
- **pipeline connecting two sites at surface**

modificato da Winsloe et al 2020

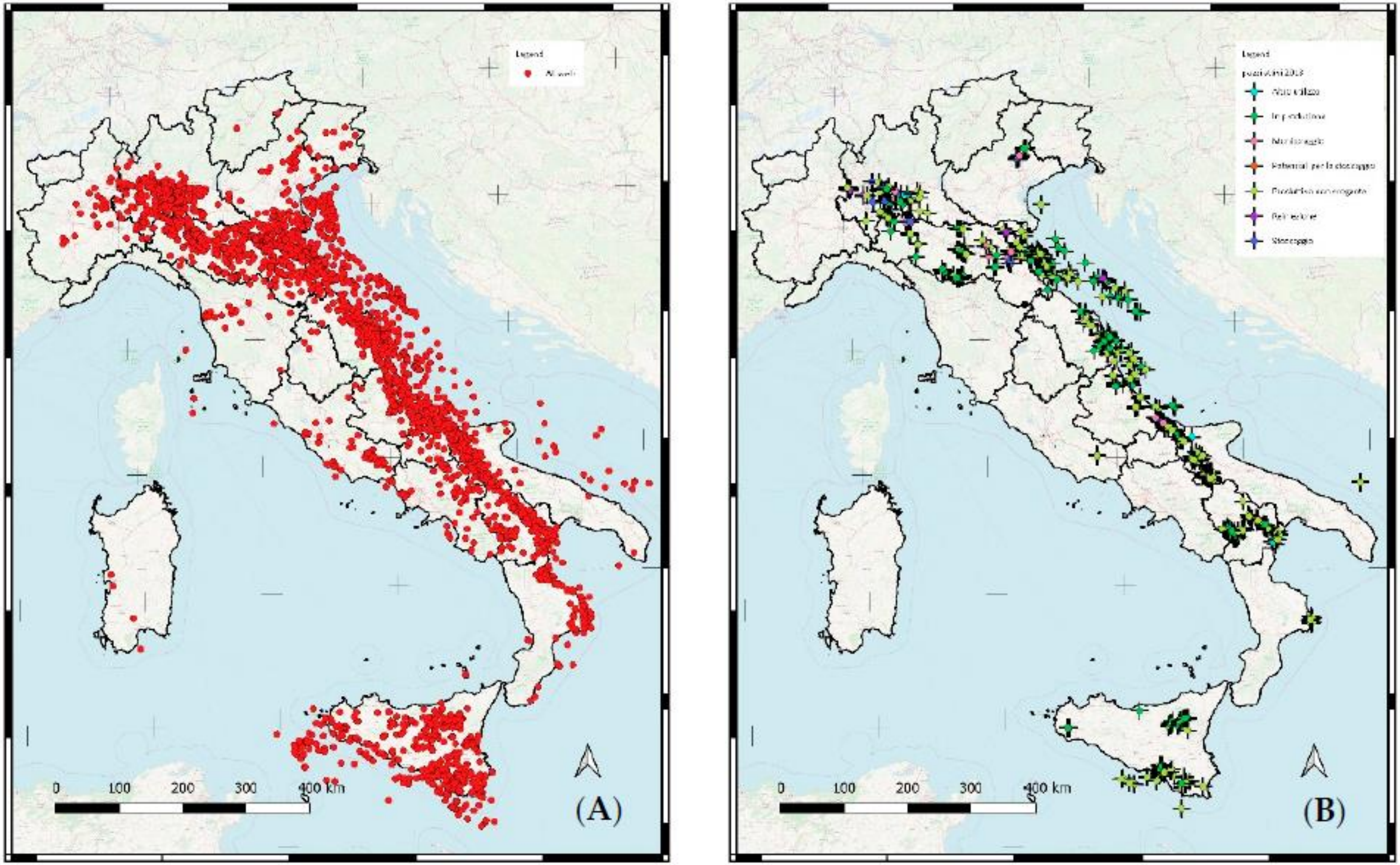
Hydrocarbon occurrence in Italy

5 major petroleum systems



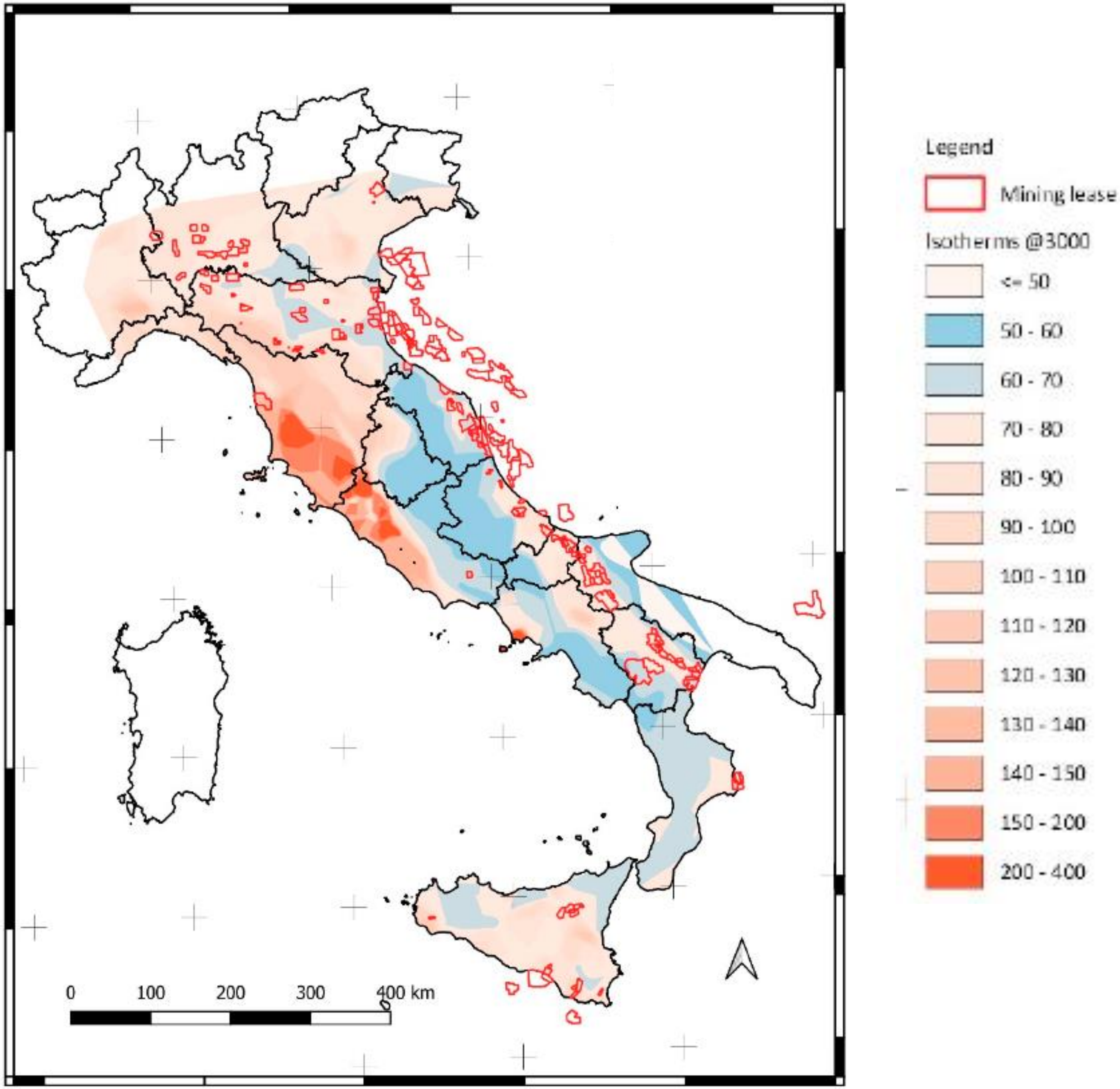


O&G wells in Italy in 2019



modificato da Soldo et al 2020

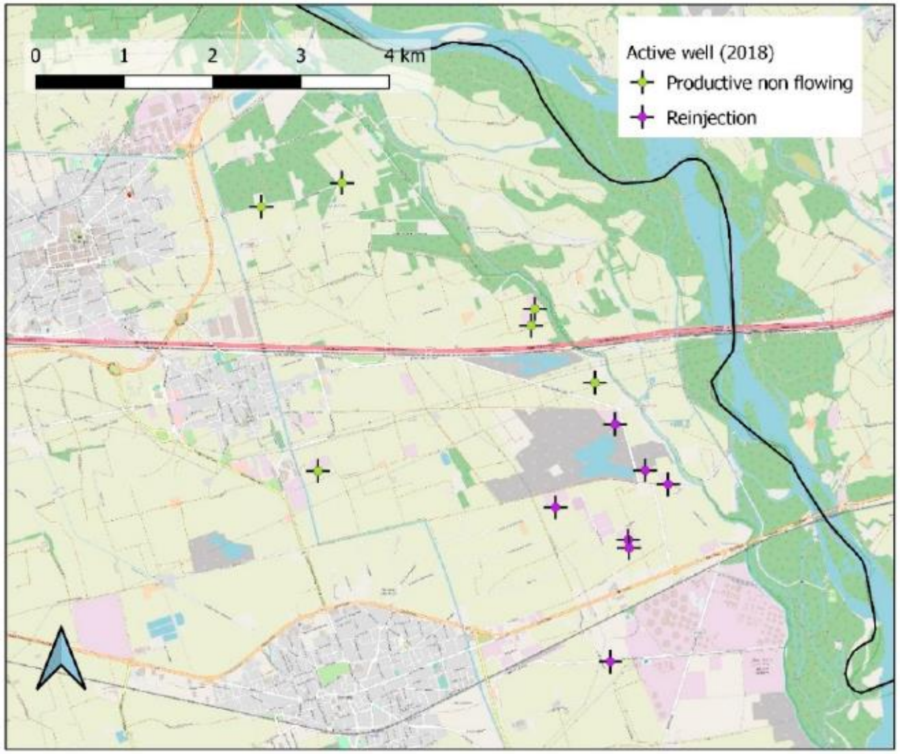
O&G wells in Italy in 2019



estimated T at −3 km below ground level

modificato da Soldo et al 2020

Villafortuna Trecate case study



the single well can :

- **produce a flow rate of 100 kg/s of hot water**
- **have a wellhead brine T of 130 °C**

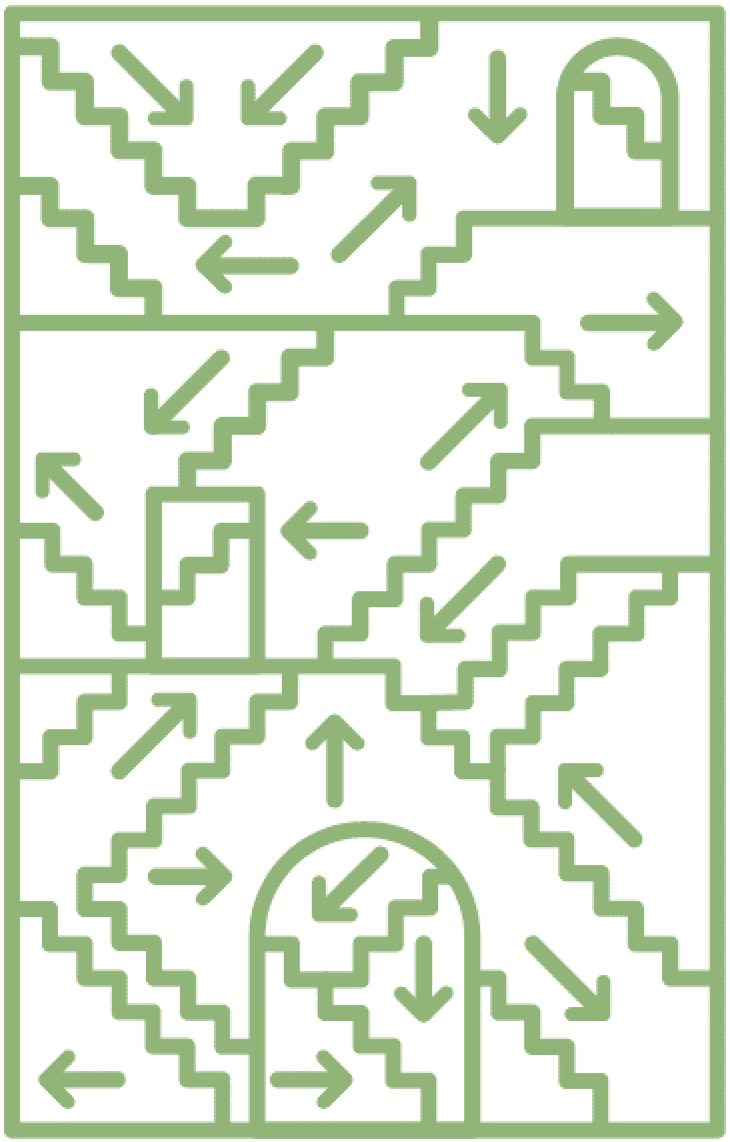
The geothermal fluid is supplied first to the ORC plant

assumed a consumption per capita of 1400 kWh per year and a heating request of 2kW per person

130 °C ORC Plant → **84 °C** DH Plant → **50 °C** aquaculture → **35 °C** aquaculture

modificato da Soldo et al 2020

administrative procedures and evaluation of geothermal projects



➢ regulatory and legal issues

- complex authorization procedures
- exploration and concession licenses
- environmental permit (EIA Environmental Impact Assessment)
- lack of centralized management and coordination between responsible bodies

➢ absence subsidies, incentives

- contributions for capital expenditures
- incentives for energy conversion

➢ well ownership to be verified

- unused sterile well

- land owner

- well with unused resource

- state / state property

- well with resource used

- entity in possession of the concession

modificato da GEOENVI Project e da Sliwa et al 2016

Legal Aspects:

Country	EIA guideline	Specifics for DGE	Scope: Environmental impacts to consider	Thresholds	Mitigation measures
Belgium	Yes	No, it is a generic guideline	The list of impact is defined by the developer. Generic guidelines included in the EIA office portal for some EIs.	Included in the regulation. The guidelines per discipline include thresholds (regulated), generic for all sectors	There is a handbook with general mitigation measures
France	Yes	Yes, for geothermal drilling	Standard list of impacts included in the general EIA require examination for DG	No, but defined in the regulation	The EIA guideline doesn't provide prescription for the mitigation of EI.
Hungary	No	No, not specifics for DG	No, but defined in the regulation	No, but defined in the regulation	N/A
Italy	No, only recommendations to avoid EI&R	No, not specifics for DG	Standard list of impacts included in the general EIA; the developer declares what does not apply	In Tuscany included in the EIA regulation.	Not in EIA regulation, prescriptions are given in the EIA decision.

modificato da GEOENVI Project

Legislative recommendations

- ✓ **single management of the entire approval procedure**
- ✓ **Best Practice Guide**
- ✓ **competent and trained administrative authorities in geothermal matters**
- ✓ **technical and financial capacity of those applying for a license to ensure the full execution of the projects**
- ✓ **Simplified EIA for deep geothermal energy**
- ✓ **define the best technologies available**
- ✓ **ensure flexibility in the authorization process (possibility of updates)**

modificato da GEOENVI Project e da Sliwa et al 2016

Sustainable Finance - life cycle analysis(LCA)

The EU taxonomy of sustainable finance identifies specific criteria for defining a project as a sustainable investment

1. **geothermal energy is recognized as a solution that contributes to mitigation and adaptation to climate change**

2. **threshold of 100g CO2e / kWh of emissions in the life cycle of energy activities has been maintained for geothermal**

The GEOENVI project (https://www.geoenvi.eu/) has developed an LCA to demonstrate that geothermal technologies are well below this level

modificato da GEOENVI Project

Sustainable Finance - life cycle analysis (LCA)

use simplified LCA models to report compliance with sustainability criteria and safeguard public acceptability

generate transparent and reproducible LCAs before the implementation of projects or once completed, to provide information to interested parties

modificato da GEOENVI Project

Social Acceptance

Geothermal energy has social acceptability problems similar to those of other renewable energy technologies.

1 sharing information

- promote transparency (pros and cons)
- select relevant information
- adapt the communication to the relevant public
- improve data sharing and accessibility to information

2 the creation of local benefits

- support the local community also with economic benefits
- support the local use of geothermal heat
- establish a development plan (training and education activities, job creation ...)

3 public participation

- promote territorial integration
- stimulate a quality dialogue
- continuous communication from the initial phase of the project
- promote co-ownership and crowdfunding

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GROUNDWATER QUALITY

water management practices, guidelines for aquifer monitoring and technical prescriptions differ between countries, need for a uniform approach

best practices for well design, monitoring, control and abstraction limit

control of aquifers (quality and quantity)

medium and long term behavior of the geothermal reservoir

re-injection of fluids when not used closed circuit system

monitoring of T thresholds and chemism for surface discharge

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AIR Quality

possible release of natural gas from geothermal fluids during well drilling and testing or during plant operation □ non-harmonic legislation between different states

define the background air quality (baseline)

air quality monitoring during drilling, flow tests in wells, production

prevent accidental gas flow (blow out preventer)

emission mitigation and abatement plans

air quality monitoring over time

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Induced seismicity

the modification of natural seismic activity during the initial development and operation of a deep geothermal project could be a concern for regulatory bodies and communities

- **the lack of common harmonized standards for seismicity based on best practices in use**
- **evidence from geothermal plants in operation indicates that this is not a problem in most cases**
- **complete description of the state of seismicity in geothermal areas in use (before and during use)**
- **good practices for the monitoring and control of seismicity**
- **guarantee data access on seismicity**

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