Tenerife Geothermal Power Project:
an energy challenge for the sustainability development of the island

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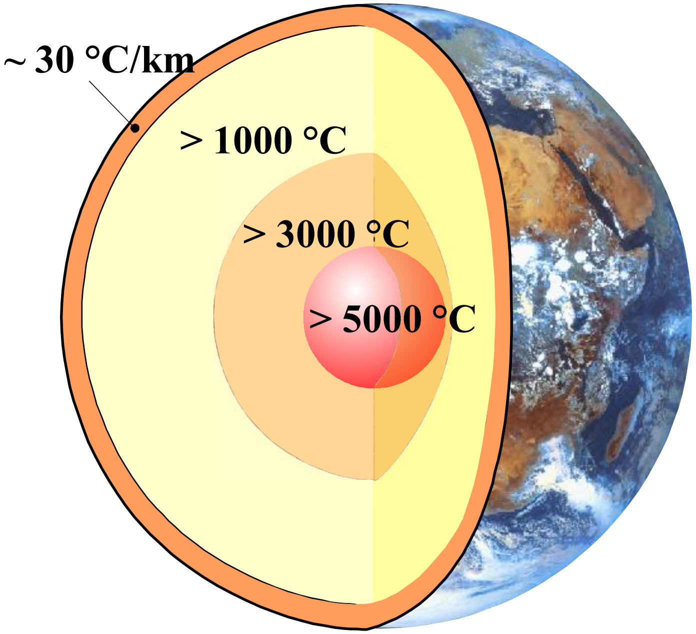
Geothermal general information

The nature of geothermal resources: The heat of the Earth



Heat is constanly produced within the Earth from decay of radioactive material.The heat is moved to the surface by heat conduction, convection or advection.

The temperature gradient is typically **30°C/km**, but can be over 200°C/km

The total amount of heat stored in the crust is of the order of 5.4 billion EJ (5.4 x 10^9 EJ).

The annual use of energy in the world is ~ 400 EJ.

If we could use 0.1% of this, it would satisfy the world energy consumption for 13.500 years.

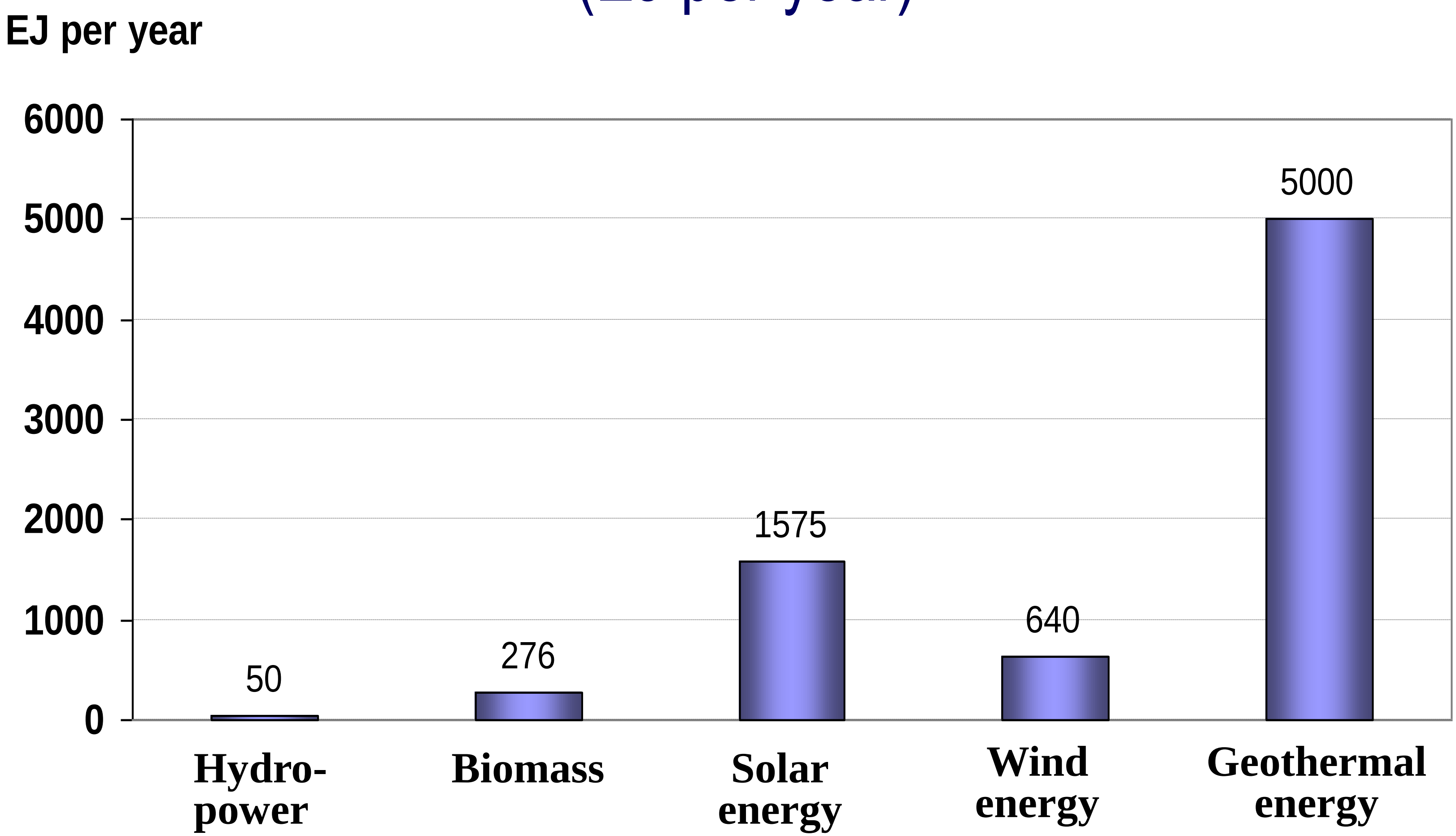
The geothermal energy resource is huge !!!

Geothermal general information

The temperature gradient is typically 30°C/km, but can be over 200°C/km ⟶ VOLCANIC AREAS

Geothermal general information

Worldwide technical potential of renewable energy sources
(EJ per year)



World Energy Assessment (2000). World Energy Assessment: energy and the challenge of sustainability. Prepared by UNDP, UN-DESA and the World Energy Council. United Nations Development Programme, New York, 508 pp

Geothermal general information

How can we extract this enormous heat?

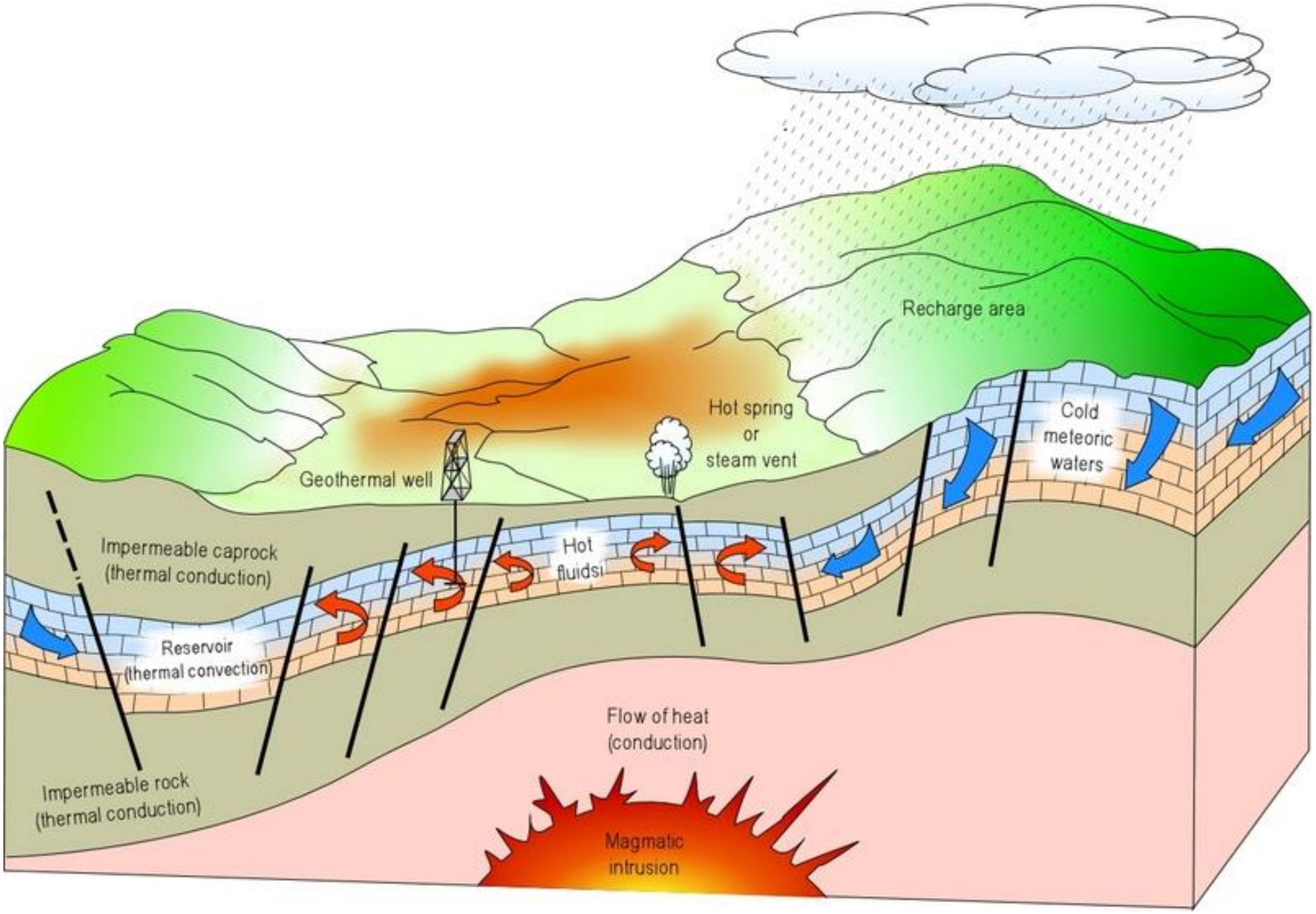
- Explore for the most appropiate subsurface conditions for geothermal produciton.

- Drill into this formations by as cheap and effective methods as possible.

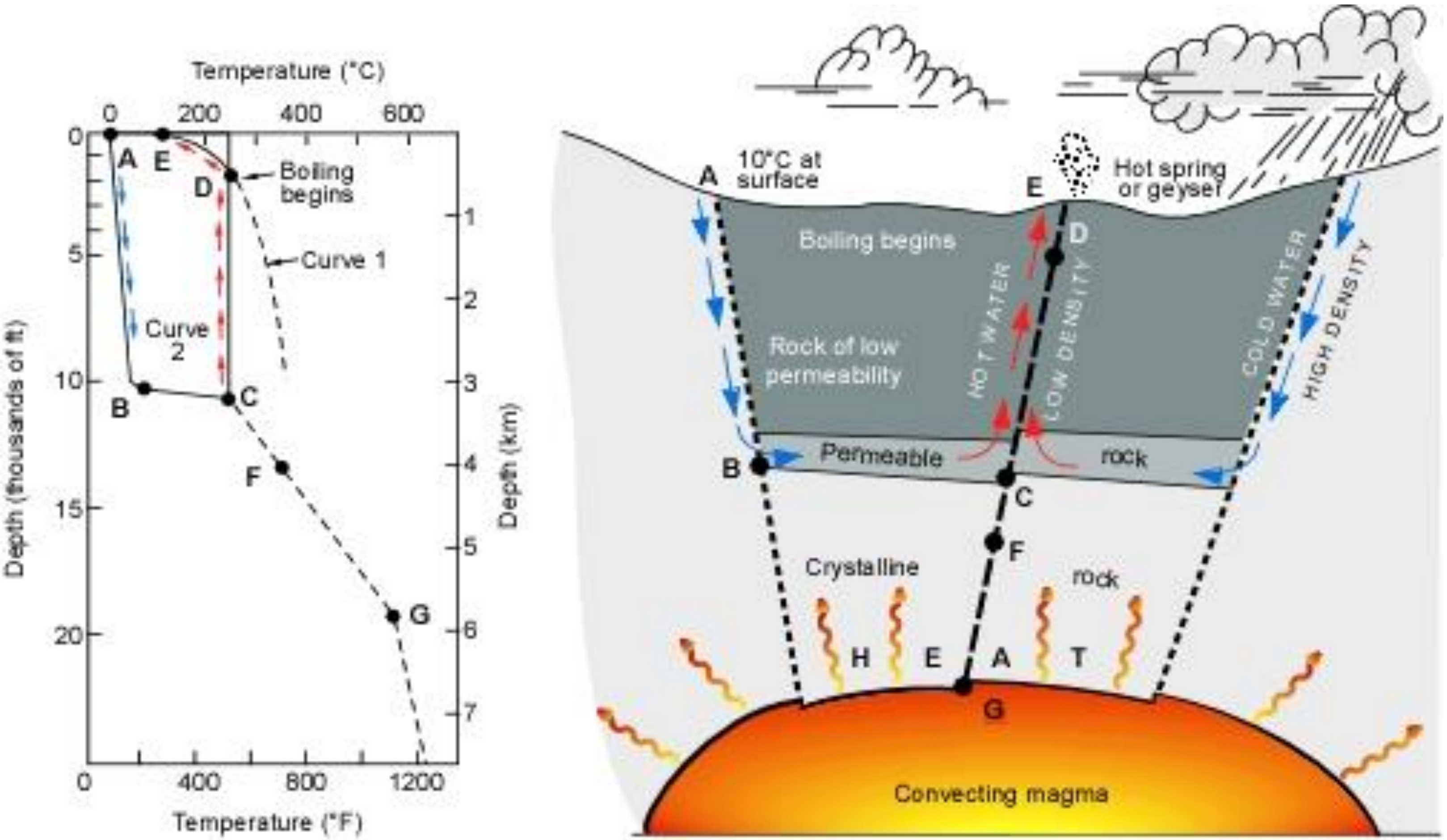
- Develop efficient methods for use of geothermal heat for direct use, electricity produciton and fuel production.

Geothermal general information

Schematic representation of an ideal geothermal system



Model of a geothermal system



Model of a geothermal system. Curve 1 is the reference curve for the boiling point of pure water. Curve 2 shows the temperature profile along a typical circulation route from recharge at point A to discharge at point E (From White, 1973)

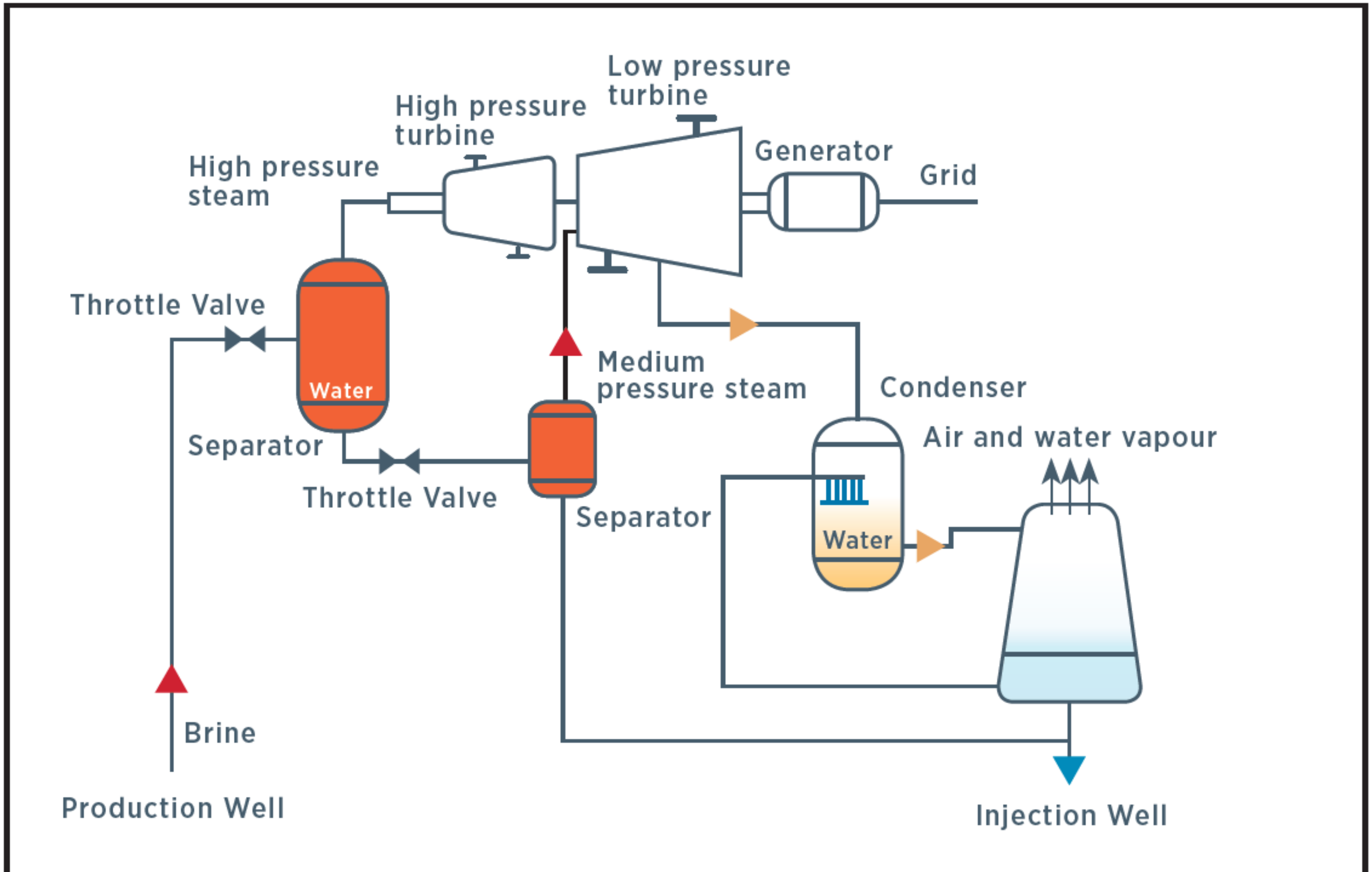
Classification of conventional geothermal resources (°C)

Type	Temperature range	Principal use
Low enthalpy resources	25º C < T < 90º C	Direct uses
Intermediate enthalpy resources	90º C < T < 150º C	• Electricity generation through Binary Cycle Power Plants • Combined applications
High enthalpy resources	T > 150º C	Electricity generation

New resources and geothermal technologies

Tecnologies	Geothermal Systems	Temperature ºC	Permeability	Uses
Geoexchange (heat pumps)	Very low temperature	< 25º	Very low Suficient - high	Direct uses
Conventional geothermal	Low temperature	25º - 90º	Suficient - high	Direct uses
	Medium temperature	90º - 150º	Suficient - high	Direct uses Electricity
	High temperature	> 150º	Suficient - high	Electricity
Geothermal new technologies	Hot Dry Rock (HDR)	>150º	Null	Electricity
	Estimulated Geothermal Systems (EGS)	Diversas temperaturas	Low	Electricity Direct uses
	Supercritical Geothermal Systems	> 350º	Suficient - high	Electricity Hydrogen

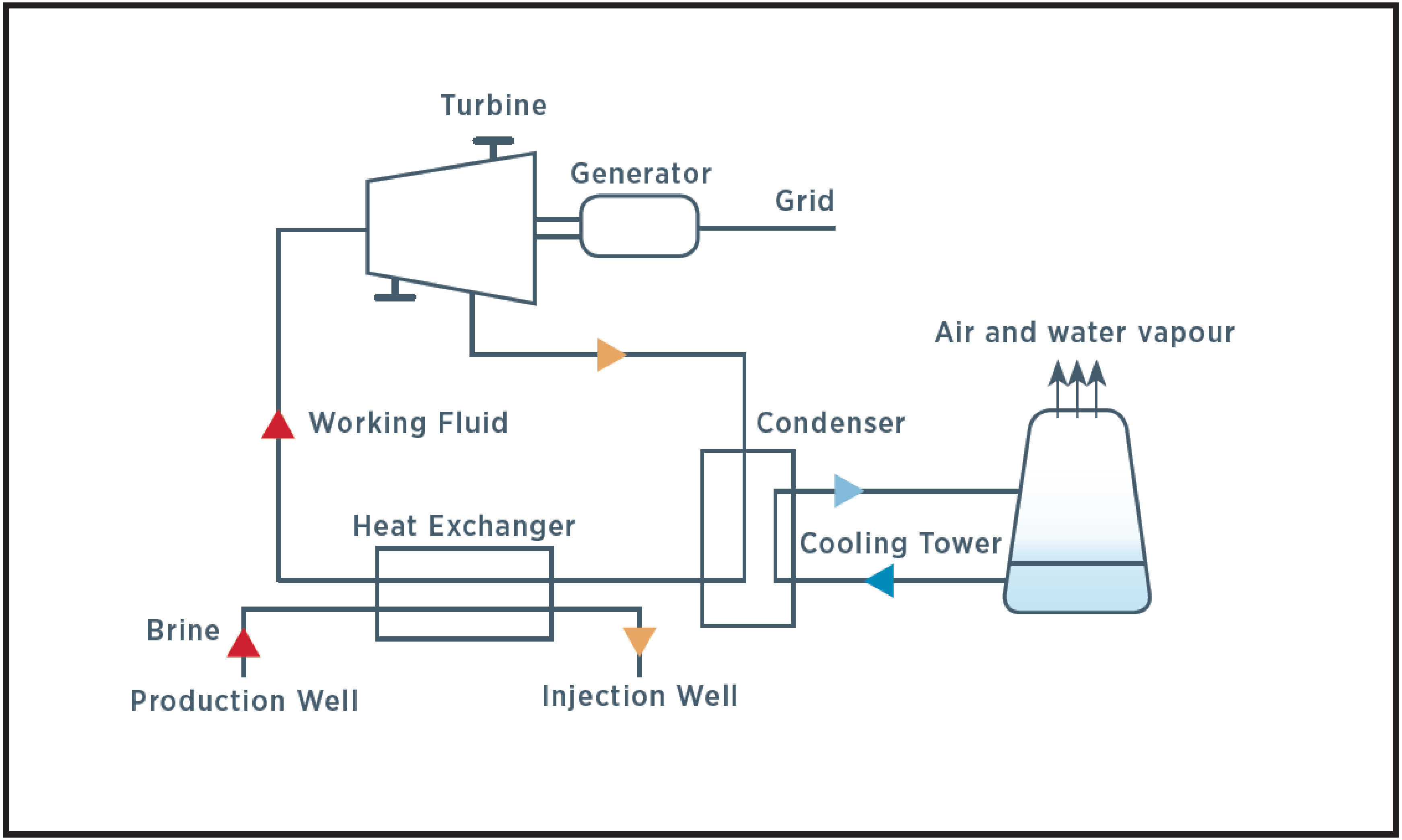
Geothermal general information



Source: IRENA, 2017c

Flash steam power plants use hot water reservoirs. In flash plants, as hot water is released from the pressure of the deep reservoir in a flash tank, some if it flashes to steam.

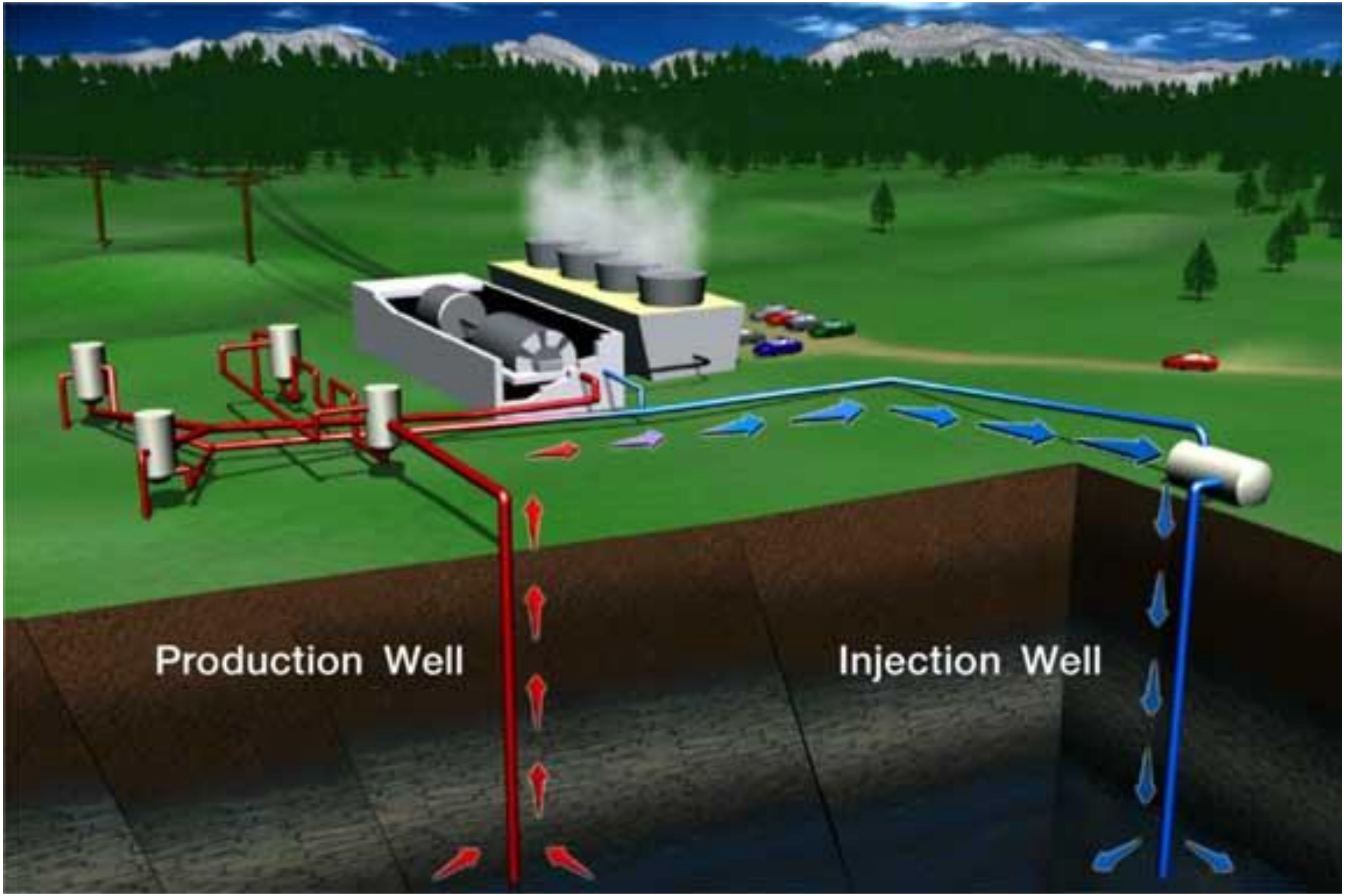
Geothermal general information



Source: IRENA, 2017c

In a binary cycle power plant (binary means two), the heat from geothermal water is used to vaporize a "working fluid" in separate adjacent pipes. The vapor, like steam, powers the turbine generator.

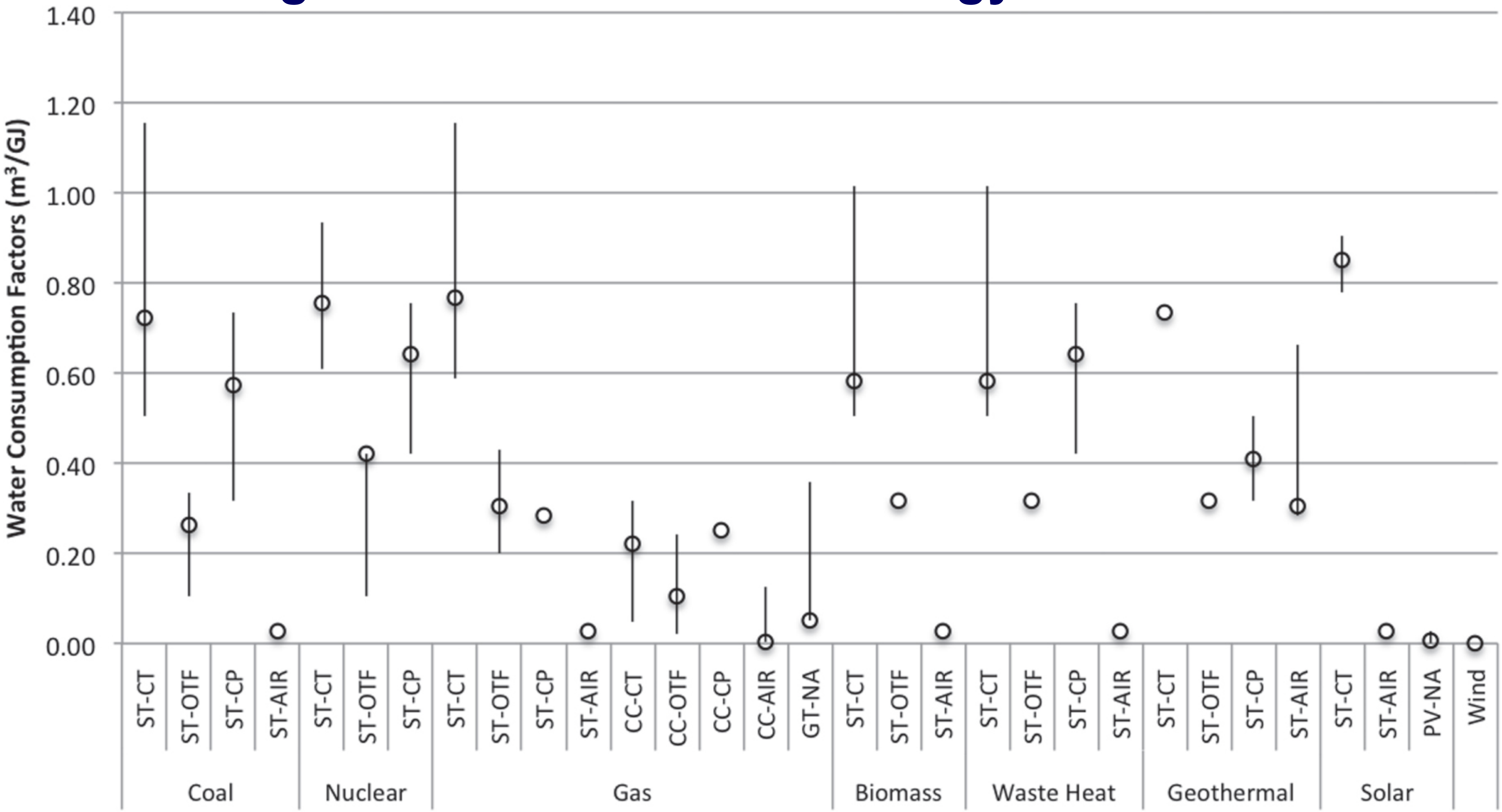
Geothermal general information



Natural steam from the production wells power the turbine generator. The steam is condensed by evaporation in the cooling tower and pumped down an injection well to sustain production.

Geothermal general information

Water Consumption Factors (m^3/GJ) related to geothermal and other energy sources



(Spang E. S. et al, 2014)

Geothermal general information

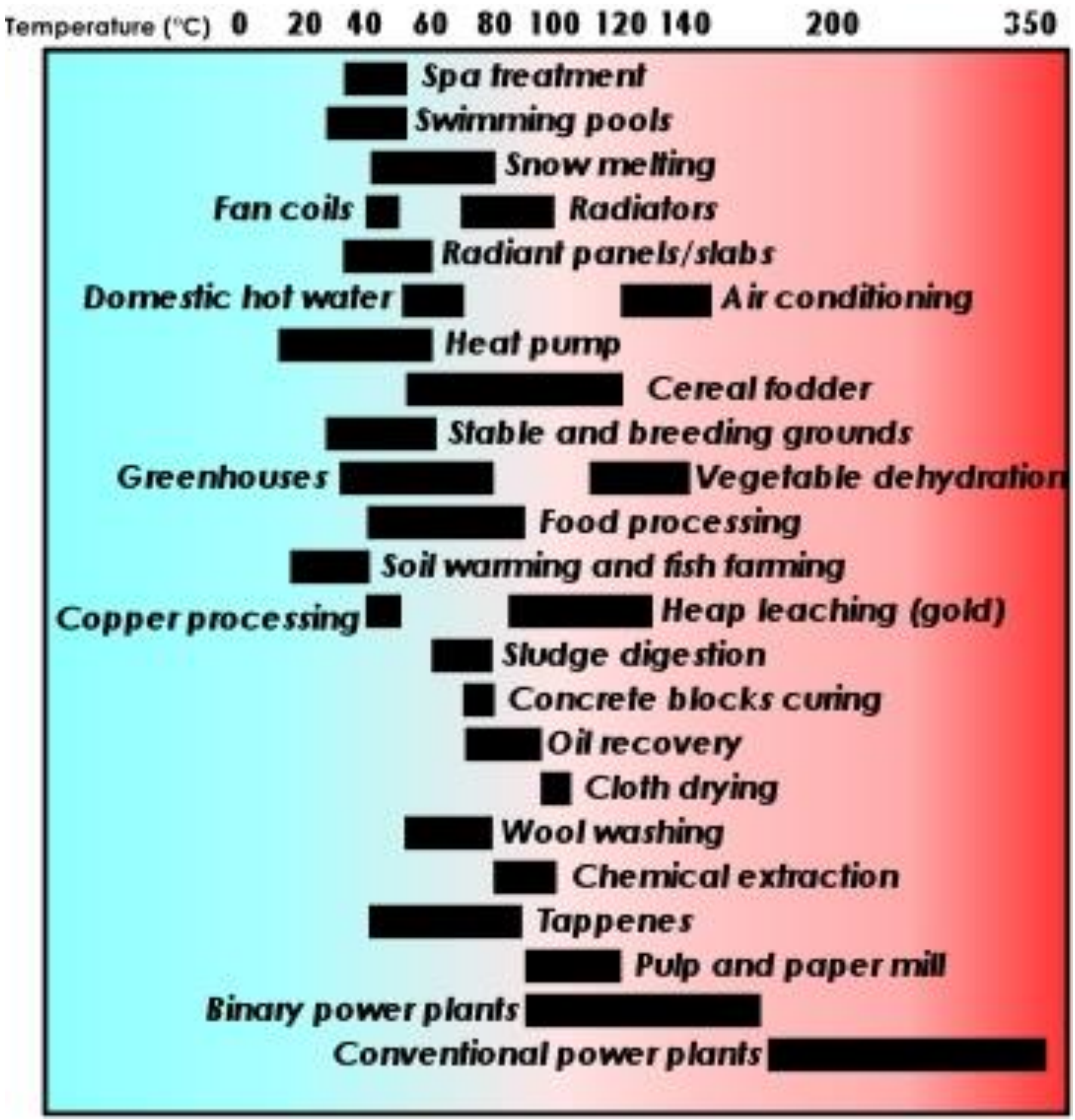


Diagram showing the utilization of geothermal fluids

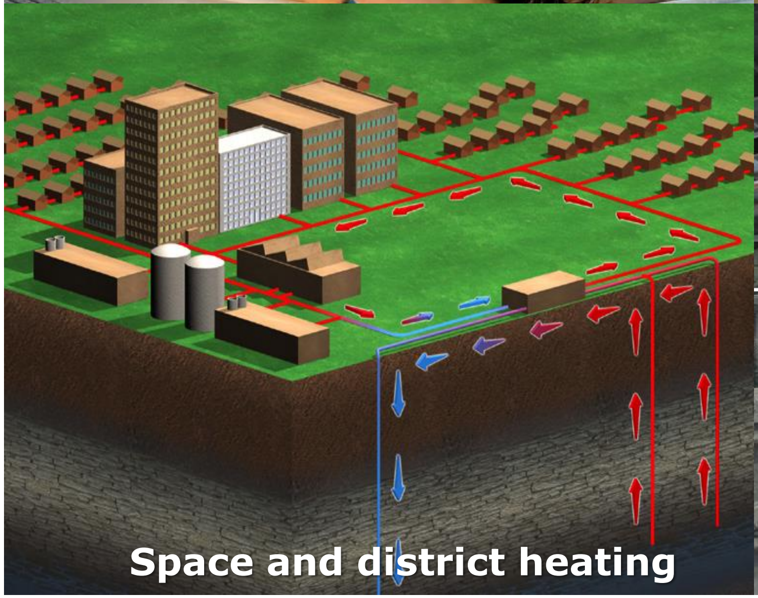
The Lindal diagram emphasises two important aspects of the utilization of geothermal resources (Gudmundsson, 1988):

(a) with cascading and combined uses it is possible to enhance the feasibility of geothermal projects

(b) the resource temperature may limit the possible uses.

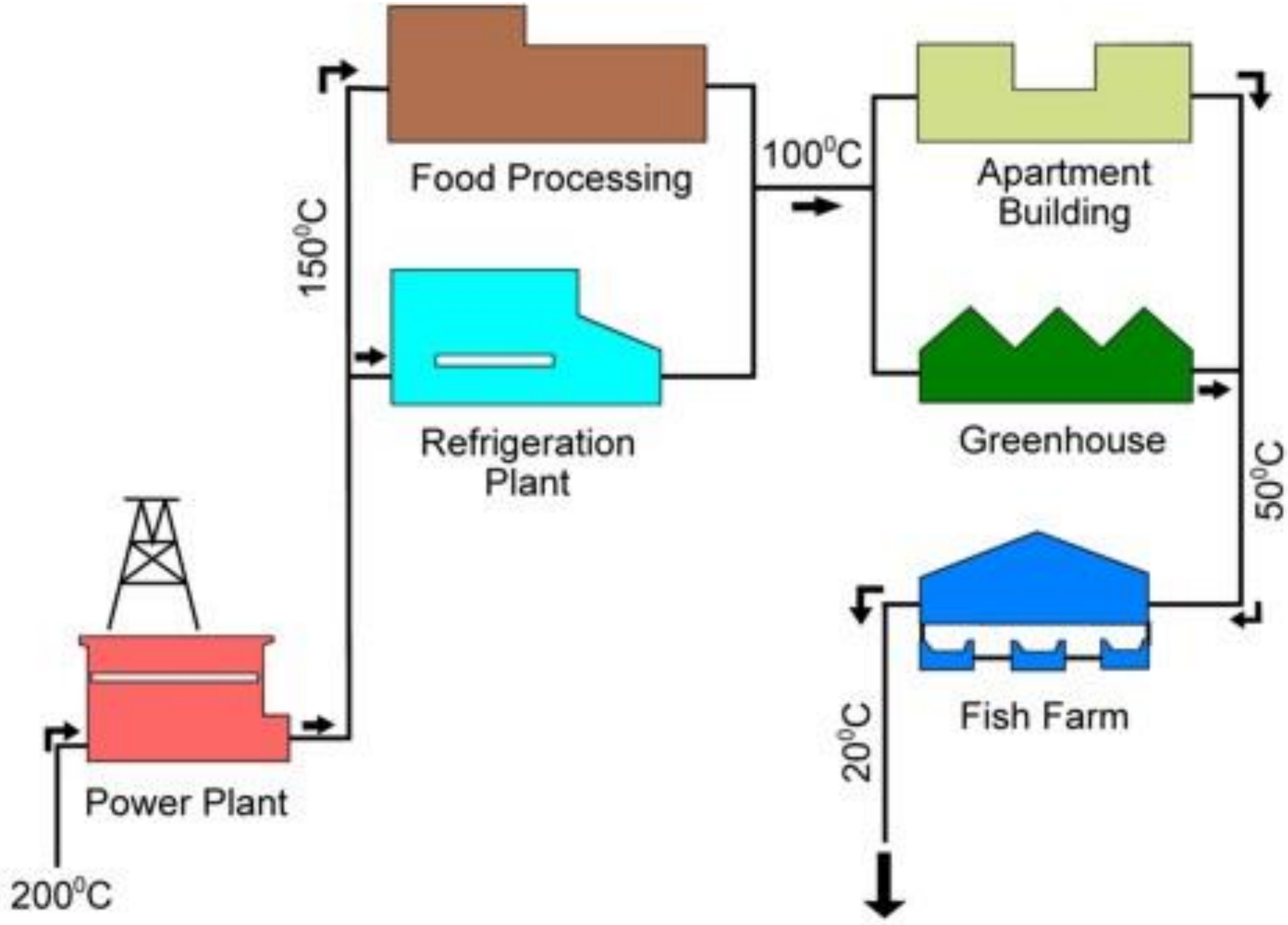
Geothermal general information

Direct Uses



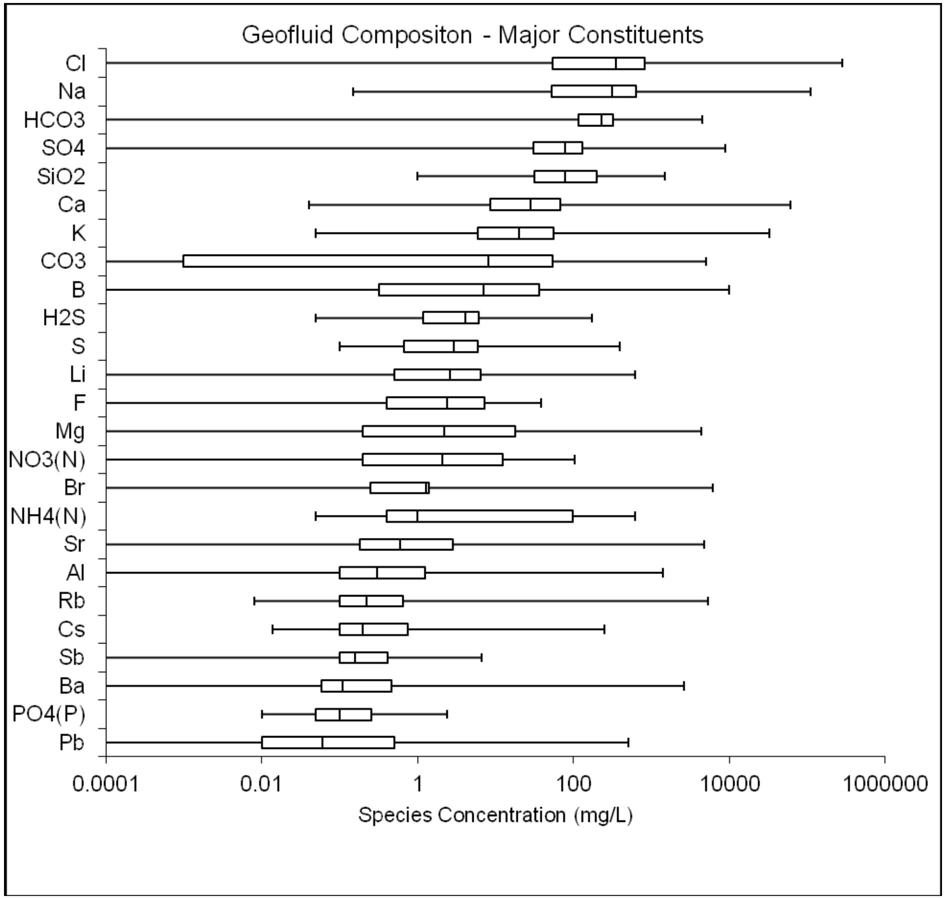
Geothermal general information

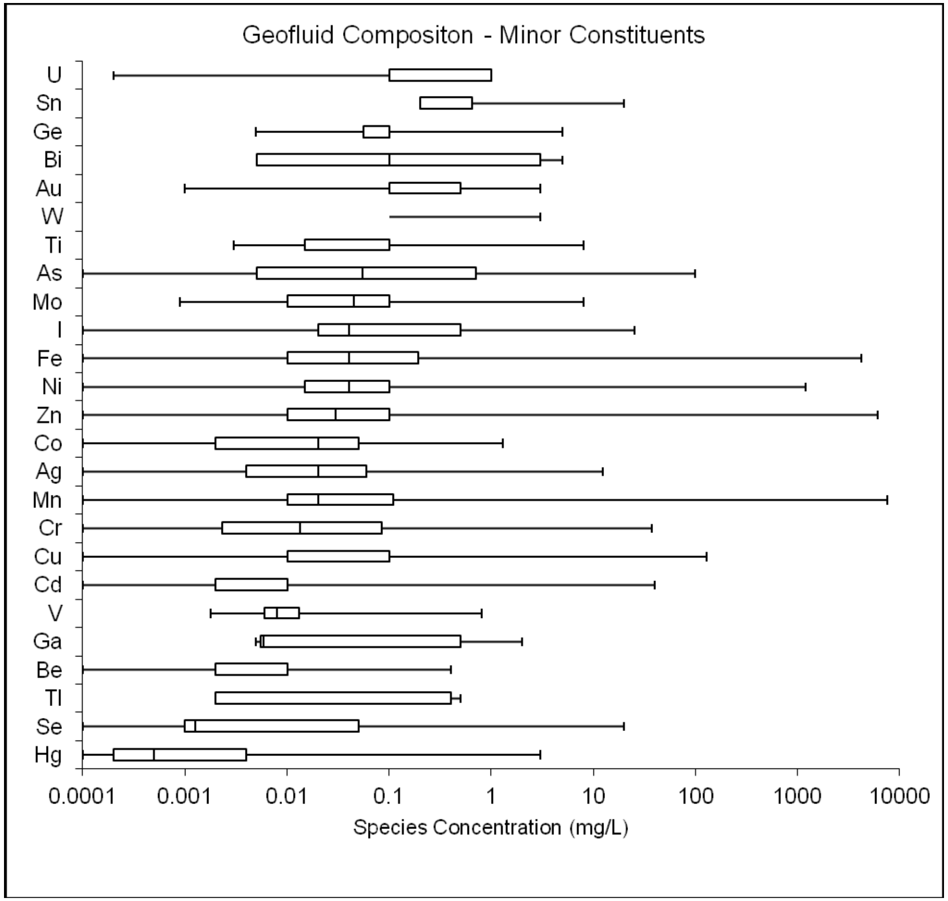
Cascading use of geothermal energy



Geothermal general information

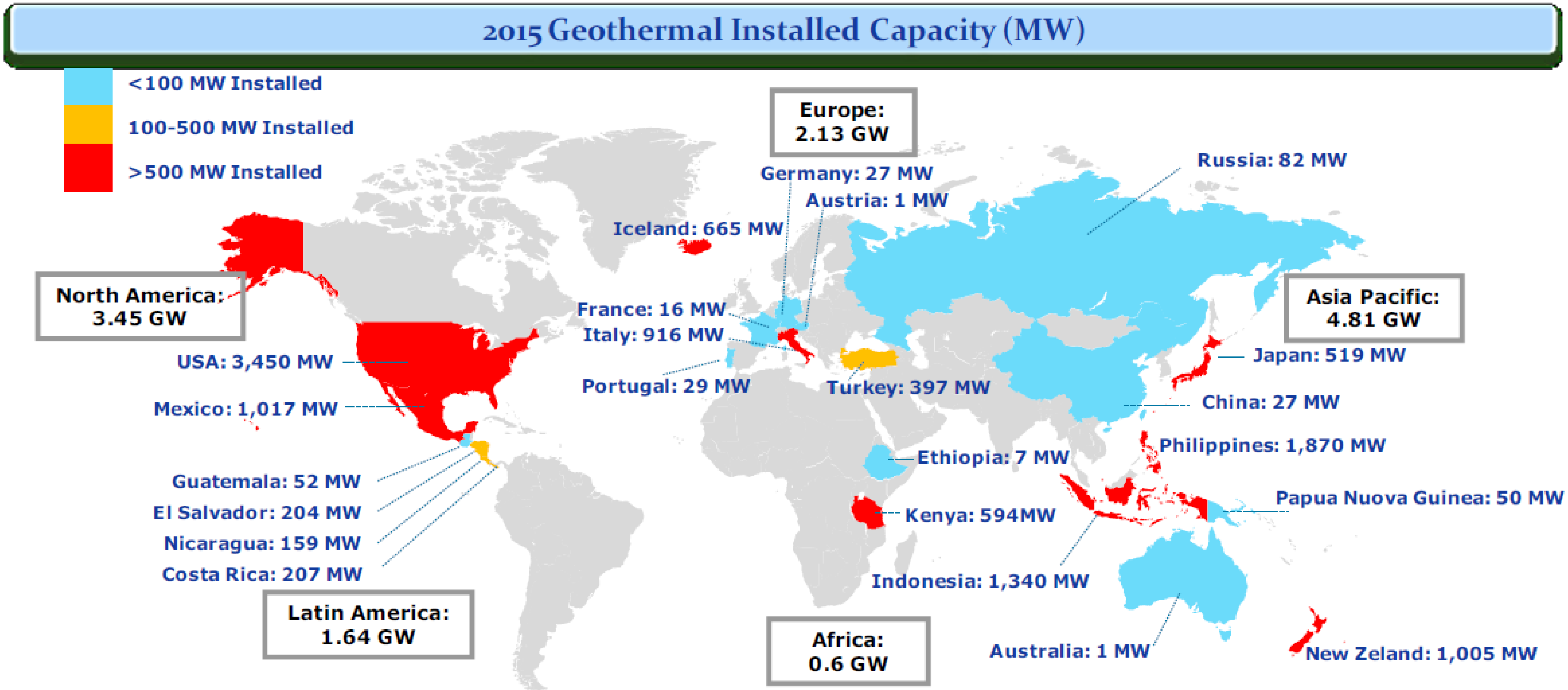
Chemical composition box plots (major and minor components) of geothermal fluids (> 90ºC)





Geothermal general information

2015 Geothermal Installed Capacity (12,6 MW)



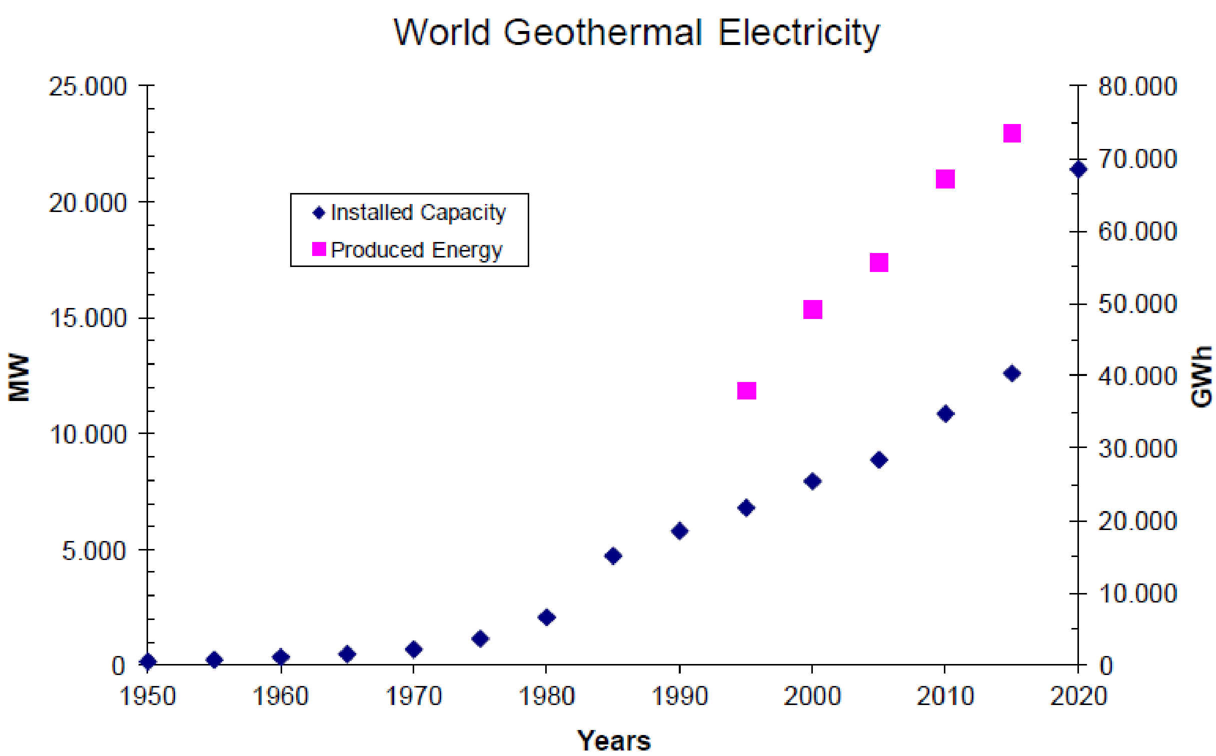
Ruggero Bertani (2015)

Geothermal general information

The total worldwide installed capacity of geothermal power plants and the produced electricity

Year	Installed Capacity MWe	Produced Energy GWh
1950	200	
1955	270	
1960	386	
1965	520	
1970	720	
1975	1,180	
1980	2,110	
1985	4,764	
1990	5,834	
1995	6,832	38,035
2000	7,972	49,261
2005	8,933	55,709
2010	10,897	67,246
2015	12,635	73,549
2020	21,443	

Total worldwide installed capacity from 1950 up to end of 2015 and short term forecasting

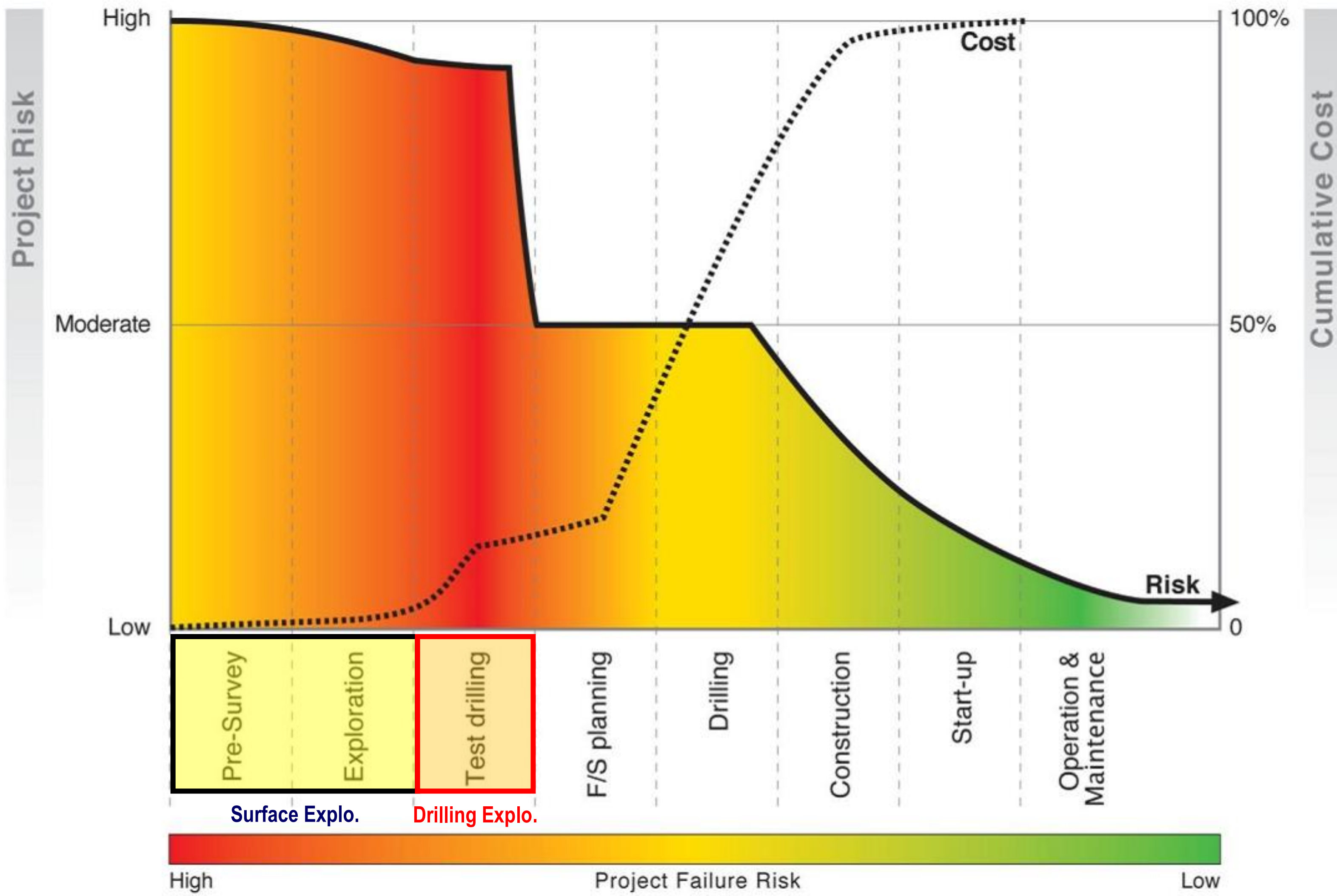


Installed capacity from 1950 up to 2015 (Left, MW) and produced electricity (Right, GWh).

Ruggero Bertani (2015)

Geothermal general information

Typical uncertainty and expenditure profiles for a geothermal project RISK *versus* COST



Methods for geothermal exploration

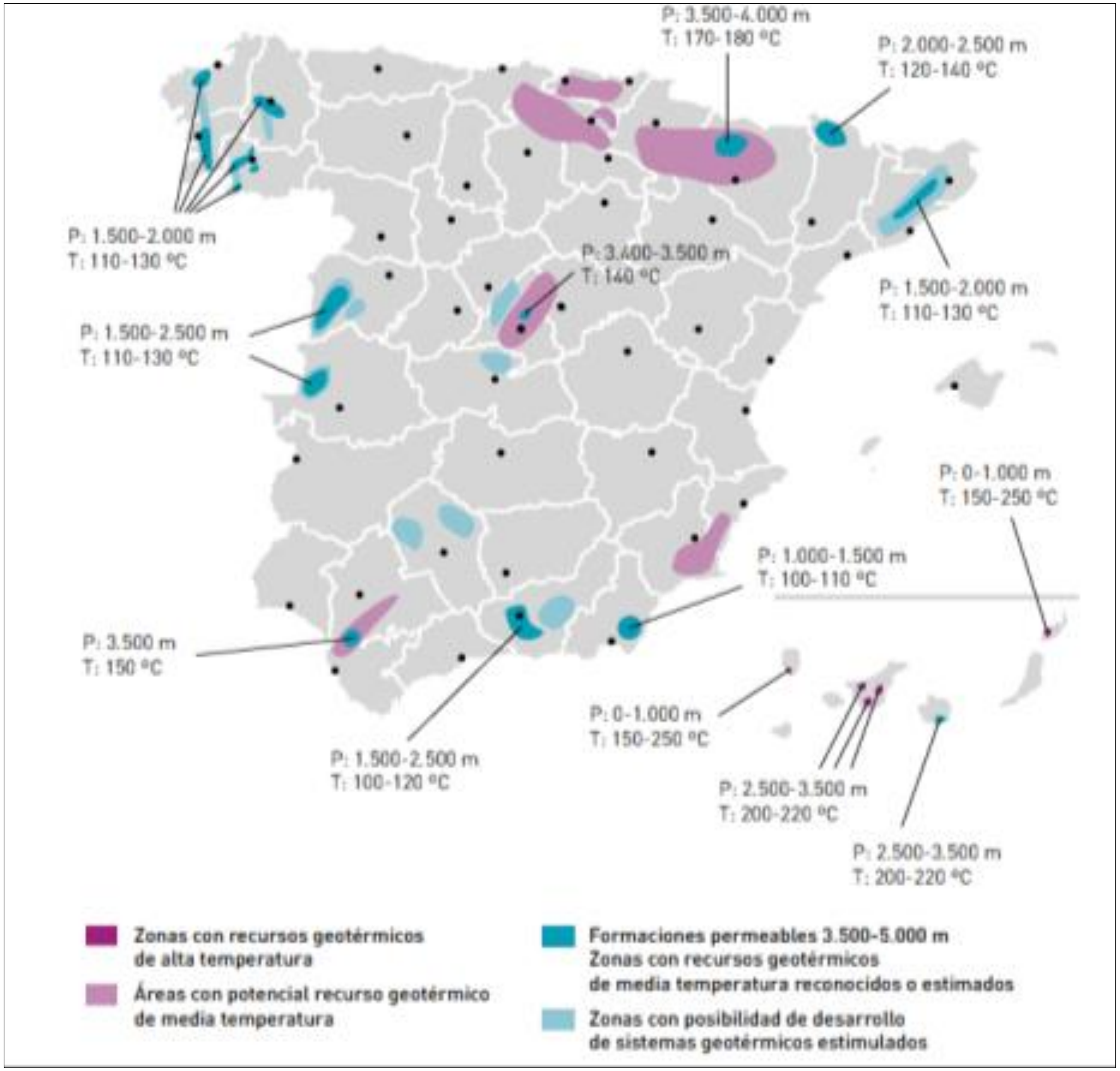
Low cost €

High cost €

- Geological and structural mapping
- Geochemical surveys
- Geophysical surveys
- Temperature gradient hole drilling

Geothermal potential in Spain

High enthalpy geothermal resources in Spain are only present in the Canary Islands



Map of medium and high temperature geothermal resources and possible stimulated geothermal systems (IDAE 2011)

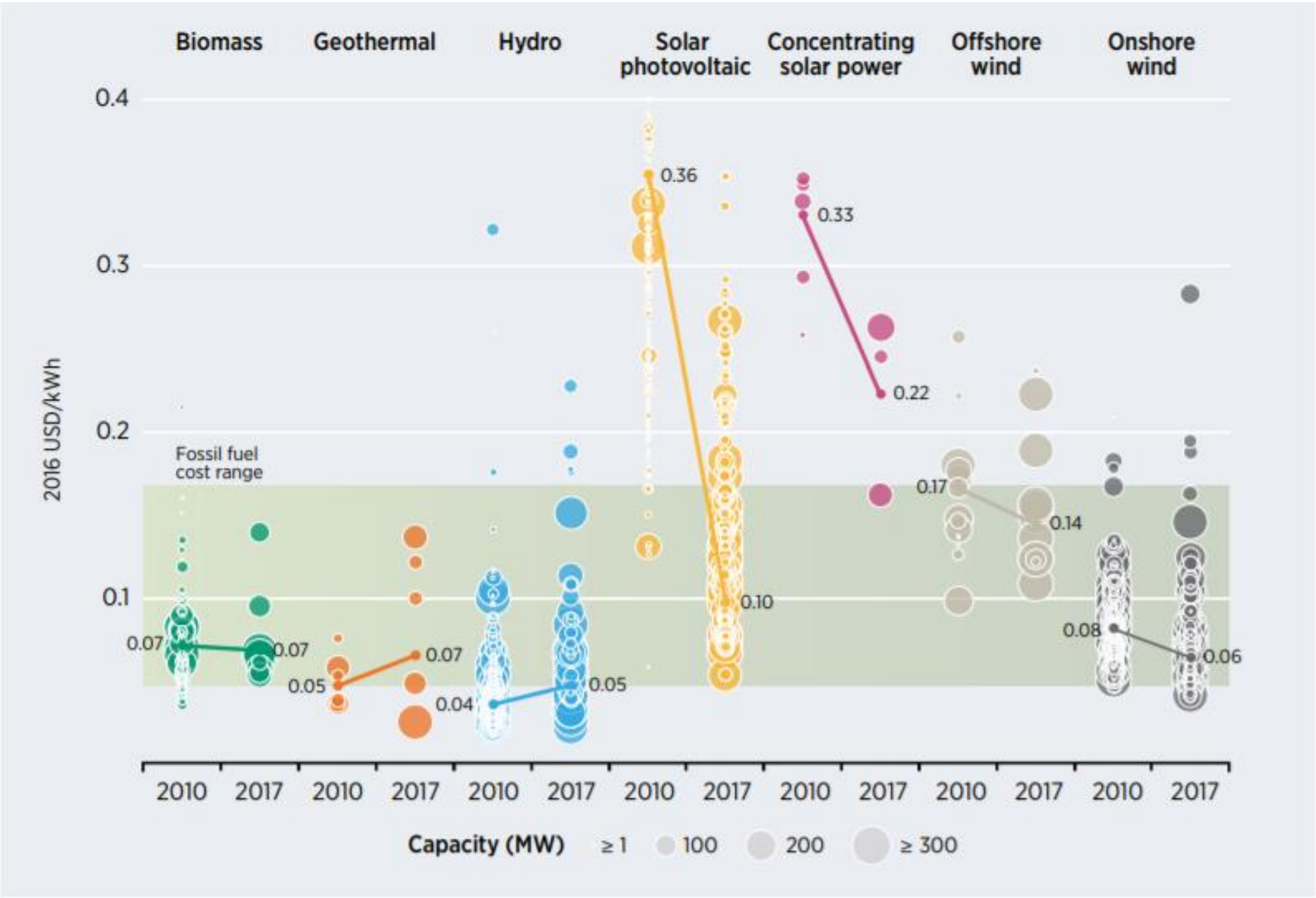
Geothermal potential in Spain

COUNTRY	Installed in 2010	Energy in 2010	Installed in 2015	Energy in 2015	Forecast for 2020	Increase since 2010			
	MWe	GWh	MWe	GWh	MWe	MWe	GWh	Capacity %	Energy %
PHILIPPINES	1,904	10,311	1,870	9,646	2,500	-34	-665	-2%	-6%
POLAND					1				
PORTUGAL	29	175	29	196	60		21		12%
ROMANIA			0,1	0,4	5	0,1	0,4		
RUSSIA	82	441	82	441	190				
SLOVAKIA					5				
SPAIN					40				
SWITZERLAND					3				
TAIWAN			0,1		1	0,1			
THAILAND	0.3	2.0	0,3	1,2	1				
TURKEY	91	490	397	3,127	600	306	2,637	336%	539%
UK					15				
USA	3,098	16,603	3,450	16,600	5,600	352		11%	
TOTAL	**10,897**	**67,246**	**12,635**	**73,549**	**21,443**				

Ruggero Bertani (2015)

Geothermal general information

Global levelised cost of electricity from utility-scale renewable power generation technologies, 2010-2017(IRENA, 2018)



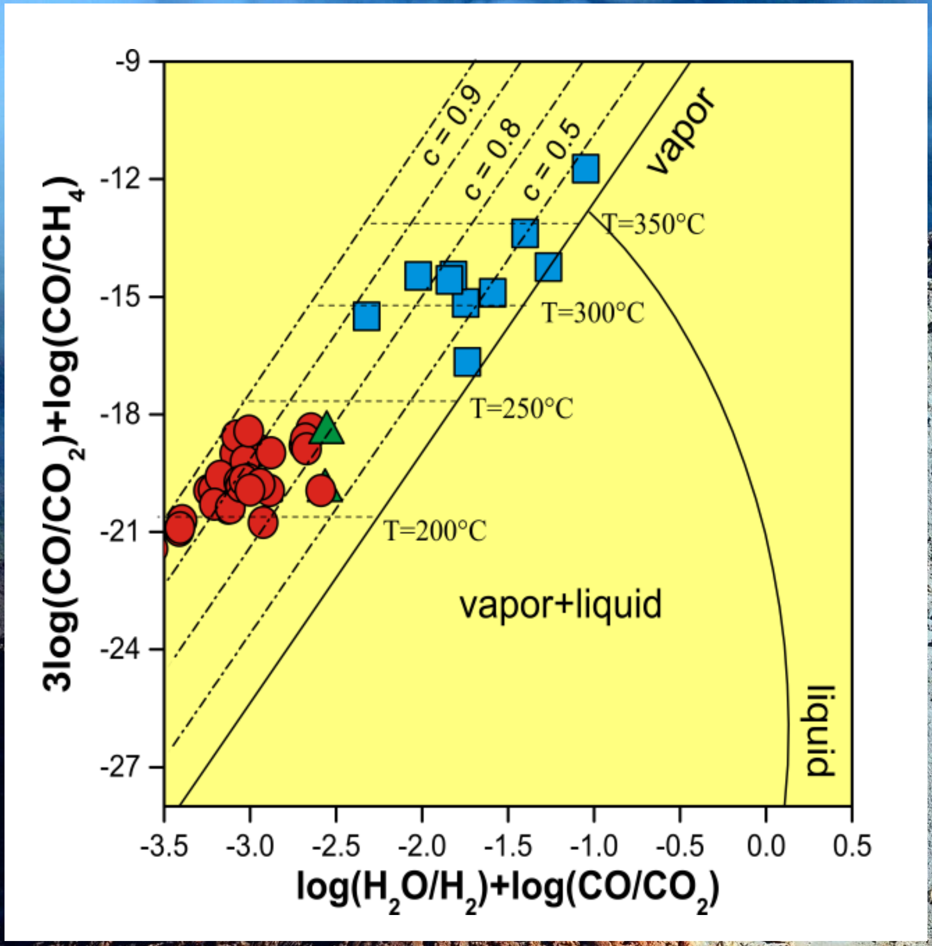
Geothermal potential in the Canary Islands

Situation of geothermal in the Canary Islands

- The Canary Islands have great geothermal potential as a consequence of their active volcanism responsible for geothermal manifestations existing in their territory (fumaroles, temperature anomalies, geochemical anomalies, etc.)
- The Canary Islands were widely studied by the Spanish Geological Survey (IGME) between 1970 -1980 with favorable results; the only region of the national territory with high enthalpy geothermal resources.
- Stoppage of research during the last almost 20 years.
- The techniques and methods of geothermal research as well as the efficiency of geothermal plants have evolved remarkably in recent years allowing the exploitation of previously unviable geothermal resources.
- A renewed interest in geothermal energy is emerging for the generation of electricity on a global scale as renewable energy on Earth, but this interest in the Canary Islands requires the necessary and sufficient support from public and/or private entities so that geothermal energy contributes to strengthen the mix energy in the Canary Islands.

Geothermal potential in Tenerife

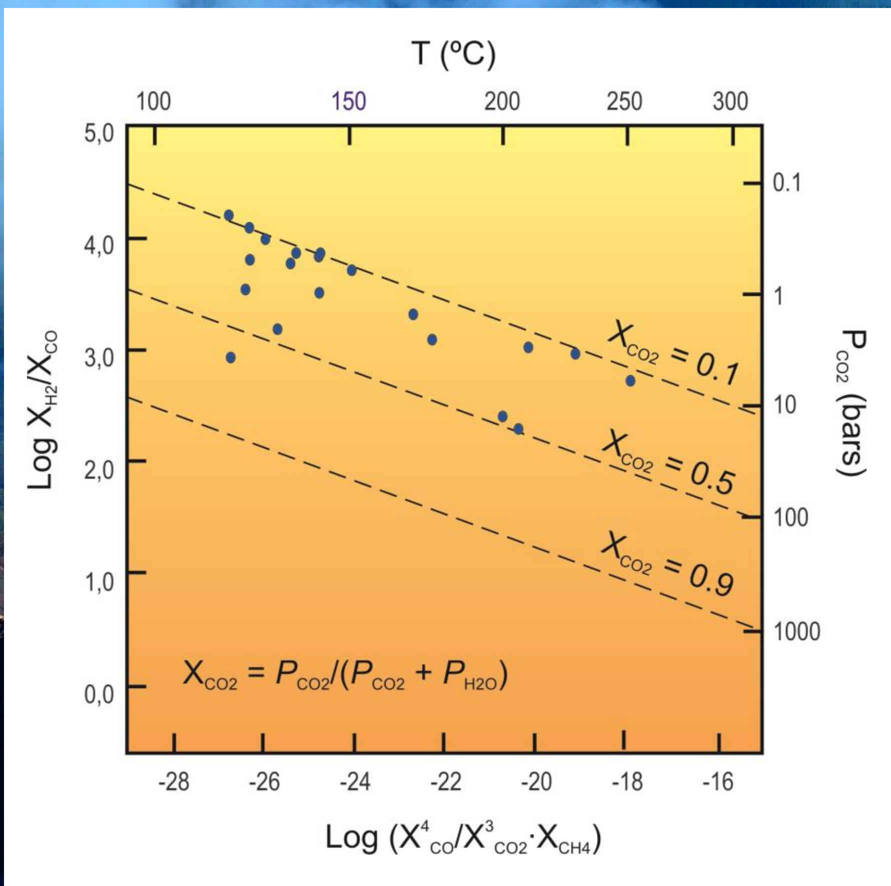
Geothermometry



Temperature
200 – 350 (°C)

Geothermal potential in Tenerife

Geobarometry



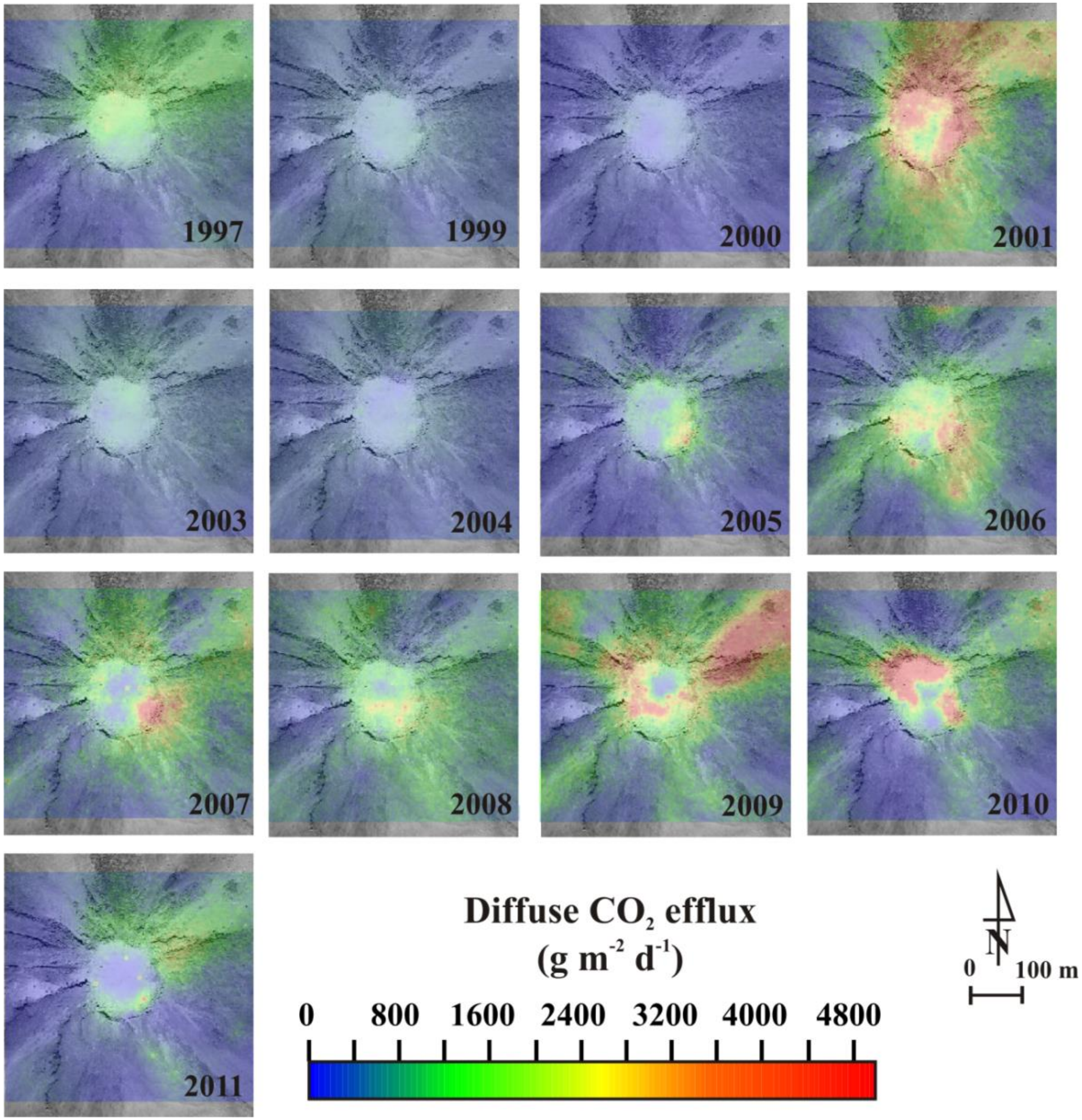
$P_{total} = P_{H20} + P_{CO2}$

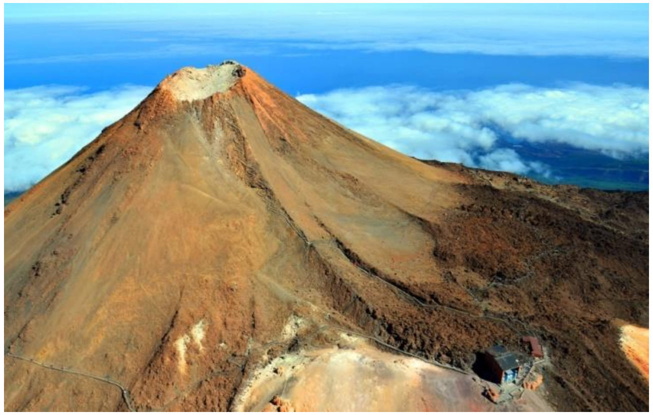
$P_{H20} \sim 40$ (bars)

$P_{CO2} \sim 2$ (bars)

$P_{total} \sim 42$ (bars)

Geothermal potential in Tenerife

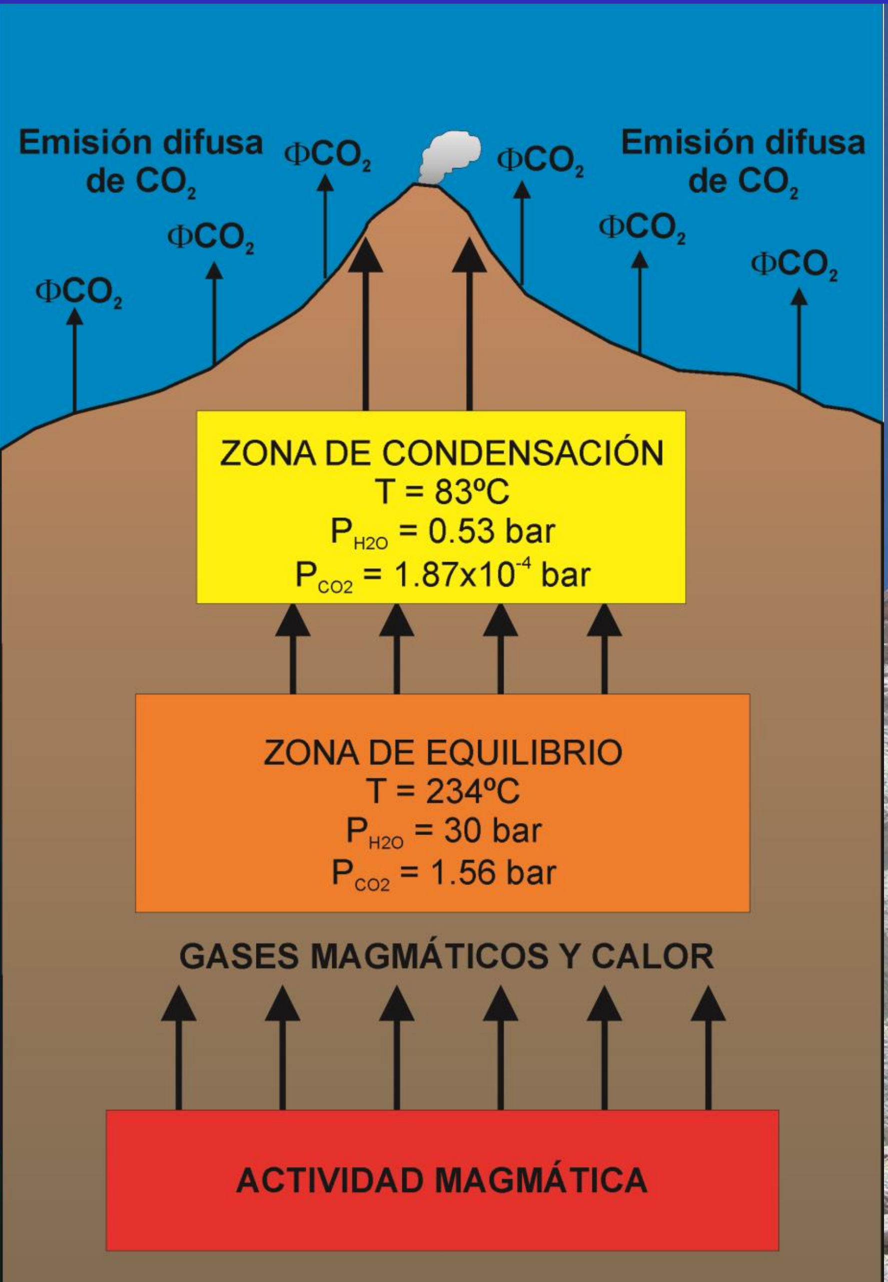


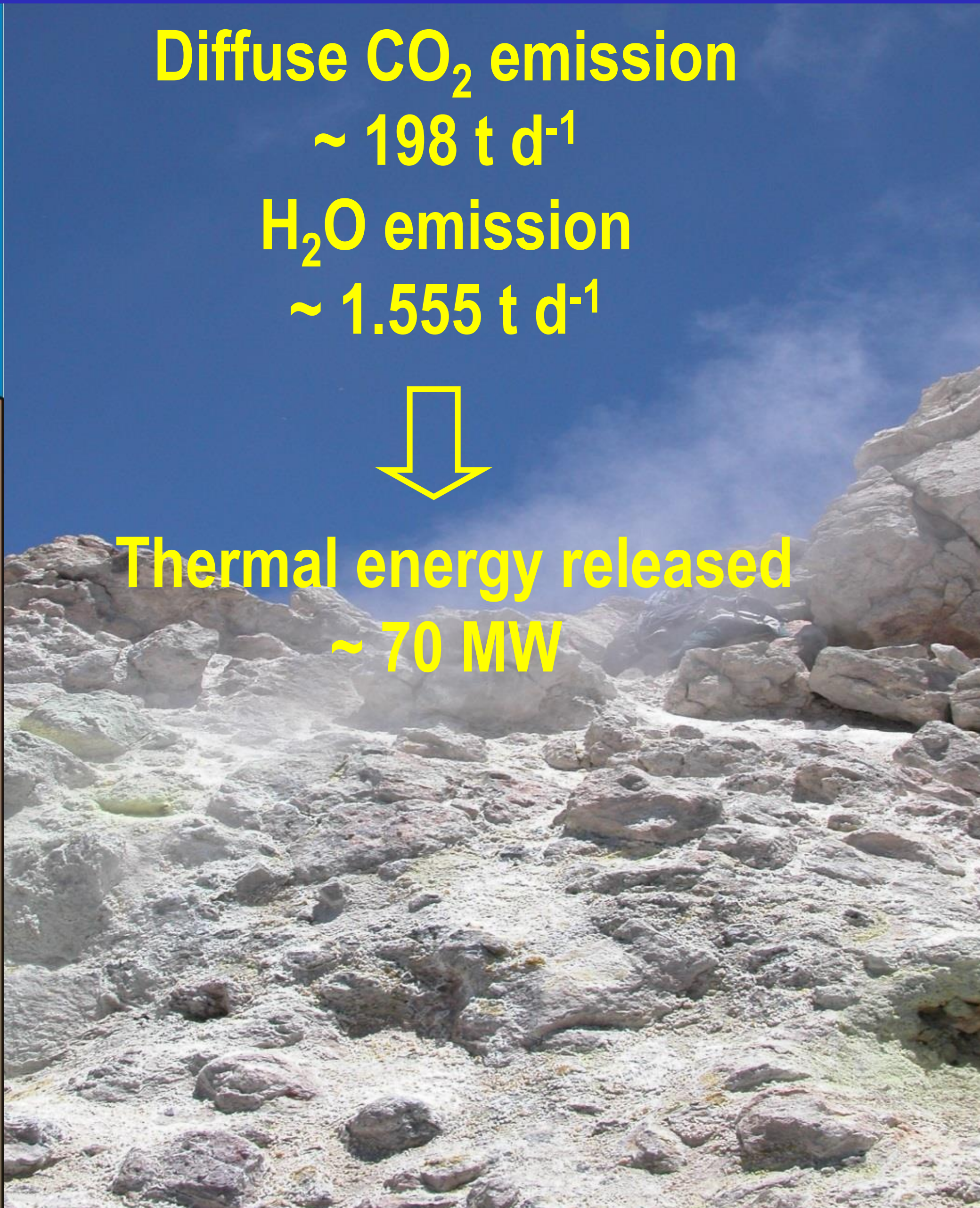


Spatial-temporal evolution of the diffuse CO_2 emission from the summit cone of Teide volcano (1997-2011)

High values !

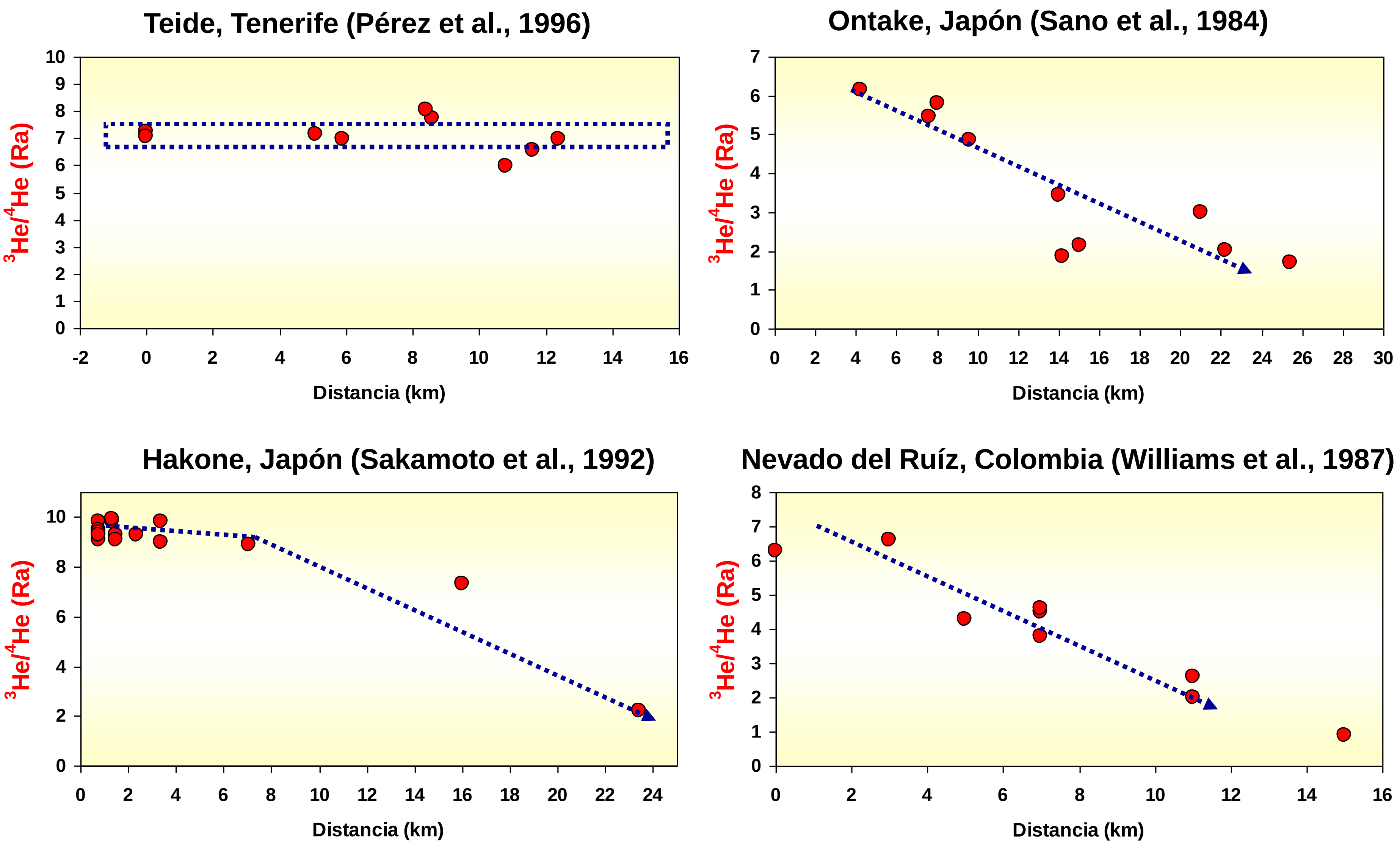
Geothermal potential in Tenerife





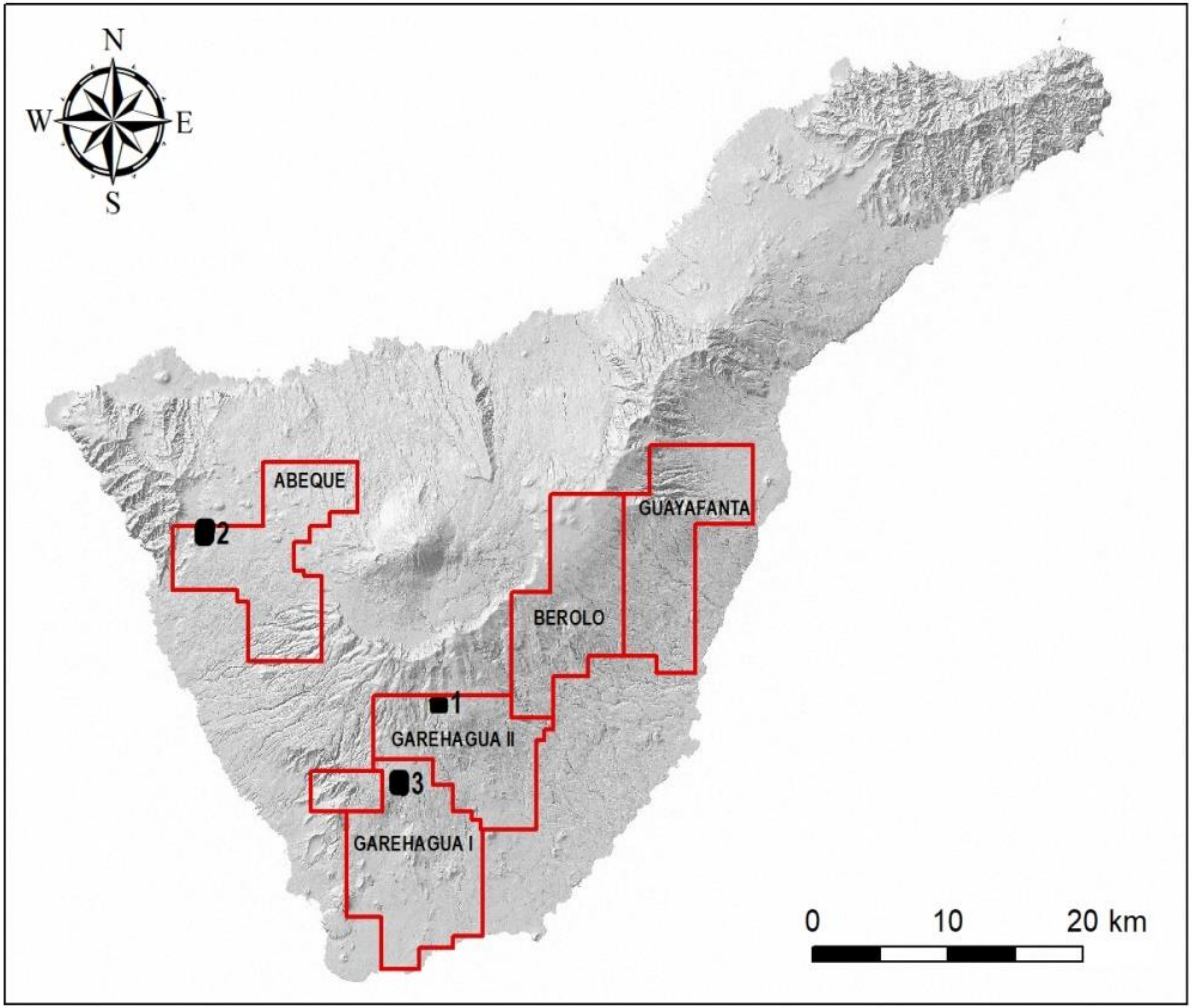
Geothermal potential in Tenerife

Helium-3 emission from stratovolcanoes



Geothermal Exploration Research in the Canary islands

Study areas for geothermal exploration at Tenerife Island



Surface Geothermal Exploration

- The objective is to obtain as much information about the properties of the geothermal system as possible, prior to drilling.

- Successful surface exploration will reduce the cost of later stages in the development and thus save a lot of money in the end

- Geothermal surface exploration is a multidisciplinary task

- Exploration strategy depends on many factors, including geological setting and temperature in the system

Geothermal Exploration Research in the Canary islands

Surv Geophys
DOI 10.1007/s10712-015-9320-8

Diffuse Helium and Hydrogen Degassing to Reveal Hidden Geothermal Resources in Oceanic Volcanic Islands: The Canarian Archipelago Case Study

Fátima Rodríguez · Nemesio M. Pérez · Eleazar Padrón · Gladys Melián · Pedro A. Hernández · María Asensio-Ramos · Samara Dionis · Gabriel López · Rayco Marrero · Germán D. Padilla · José Barrancos · Raúl Hidalgo

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Abstract We report herein the results of soil gas geochemistry studies, focused mainly on nonreactive and/or highly mobile gases such as He and H_2, in five mining licenses at Tenerife and Gran Canaria, Canary Islands, Spain, during 2011–2014. The primary objective was to sort the possible geothermal potential of these five mining licenses, thus reducing the uncertainty inherent to the selection of the areas with highest geothermal potential for future exploration works. By combining the overall information obtained by the statistical–graphical analysis of the soil He and H_2 data, the spatial distribution of soil gas concentrations and the analysis of selected chemical ratios of the soil gas to evaluate the influence of deep-seating degassing, two of the five mining licenses (*Garehagua* and *Abeque*, both located in Tenerife Island) seemed to show the highest geothermal potential. These results will be useful for future implementation and development of geothermal energy in the Canaries, the only Spanish territory with potential high-enthalpy geothermal resources, thus the most promising area for high-enthalpy geothermal installations.

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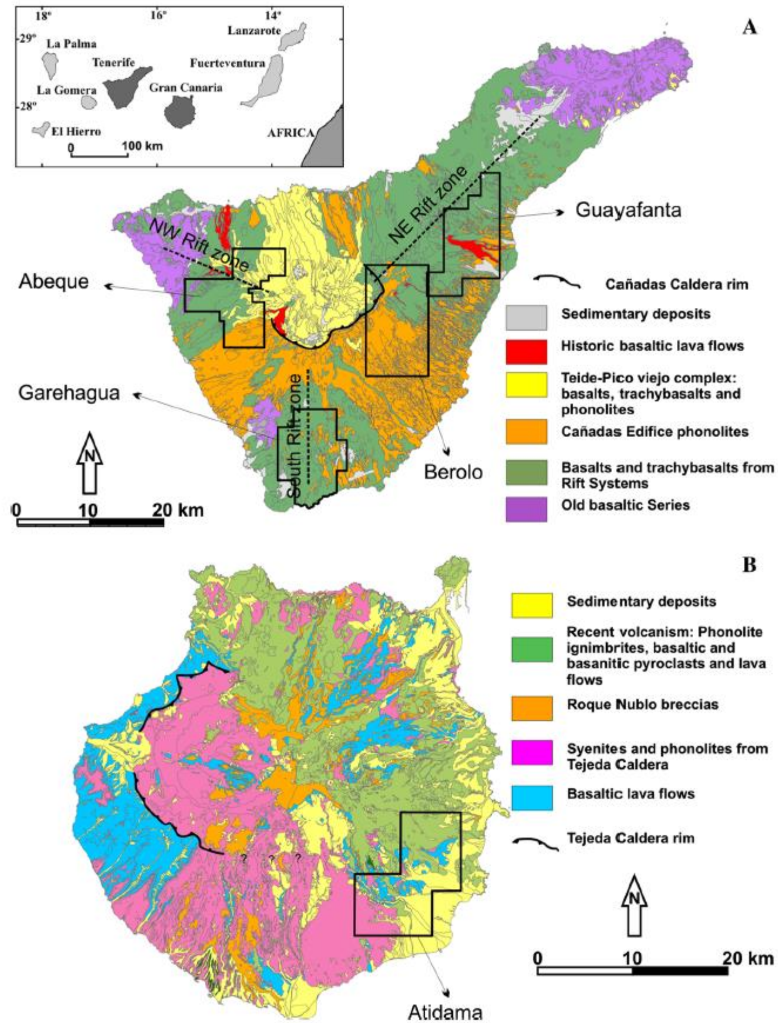


Fig. 1 Geographic location of the Canary Islands and simplified geological maps (modified from IGME, 2011) of a Tenerife, with the location of the four mining licenses (*Garehagua*, *Berolo*, *Guayanta* and *Abeque*) studied for geothermal exploration purposes and b Gran Canaria with the location of *Atidama*, the mining license studied for geothermal exploration purposes on that island

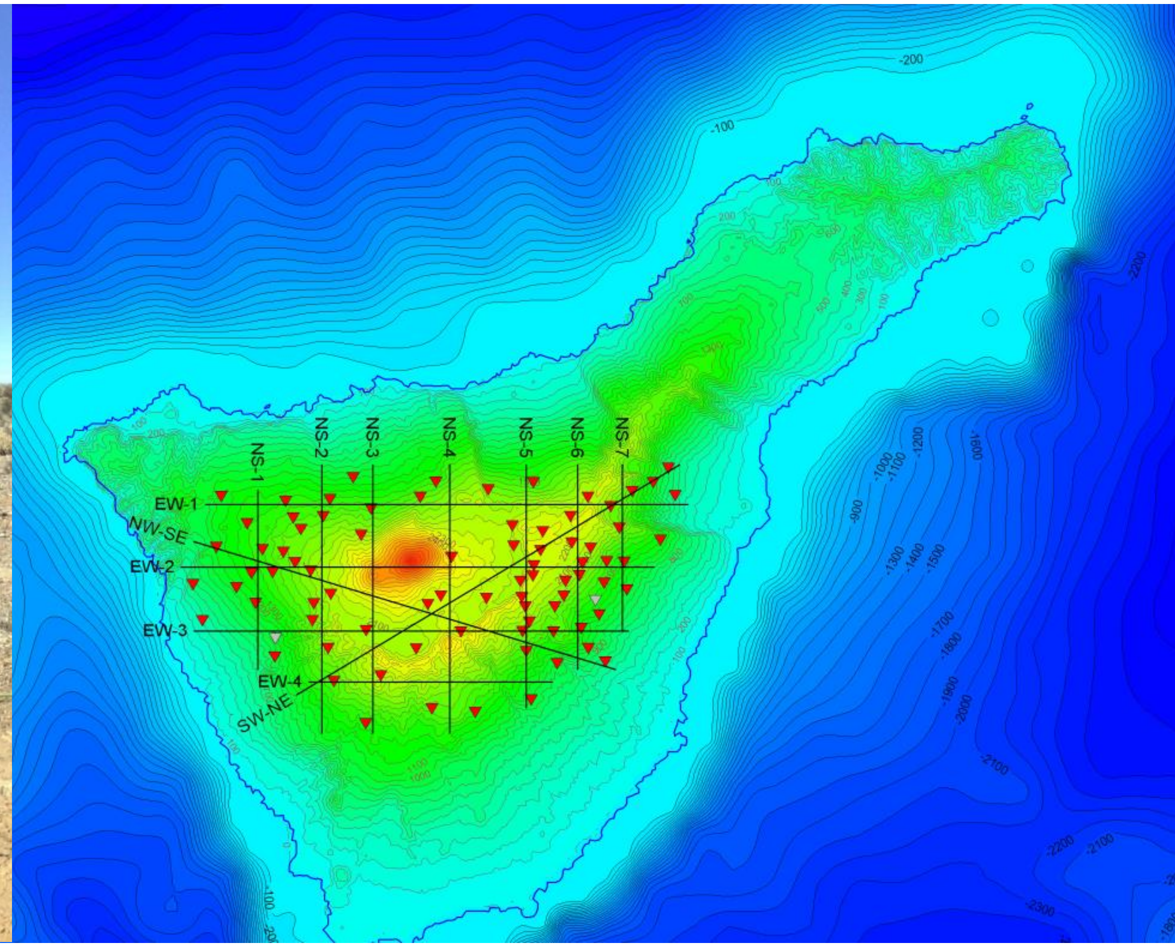
Geothermal Exploration Research in the Canary islands

Geochemical and geographical characteristics of the mining licenses

Islands	Tenerife				Gran Canaria
Geothermal mining license	**Abeque**	**Garehagua**	**Berolo**	**Guayafanta**	**Atidama**
Area (km^2)	102	100	130	103	104
# Sampling sites	406	557	577	541	600
He mean peak pop. (x background pop.)	1.57	1.70	1.53	-	1.15
Value for He[a]	**2**	**1**	**3**	**5**	**4**
H_2 mean peak pop. (x background pop.)	8.23	18.84	3.25	3.24	3.79
Value for H_2[a]	**2**	**1**	**4**	**5**	**3**
He/Ar ratio (>3 x air value) (%)	0.57	0.18	0.00	0.00	0.00
Value for He/Ar[a]	**1**	**2**	**5**	**5**	**5**
He/Ne ratio (>3 x air value) (%)	0.80	0.18	0.00	0.00	0.00
Value for He/Ne[a]	**1**	**2**	**5**	**5**	**5**
H_2/Ar ratio (>3 x air value) (%)	2.00	19.96	39.64	1.11	41.97
Value for H_2/Ar[a]	**4**	**3**	**2**	**5**	**1**
Value for N_2-Ar-He diagram[a]	**1**	**2**	**2**	**3**	**3**
Value for N_2-Ar-H_2 diagram[a]	**2**	**1**	**2**	**3**	**3**
Total geochemical values	**13**	**12**	**23**	**31**	**24**

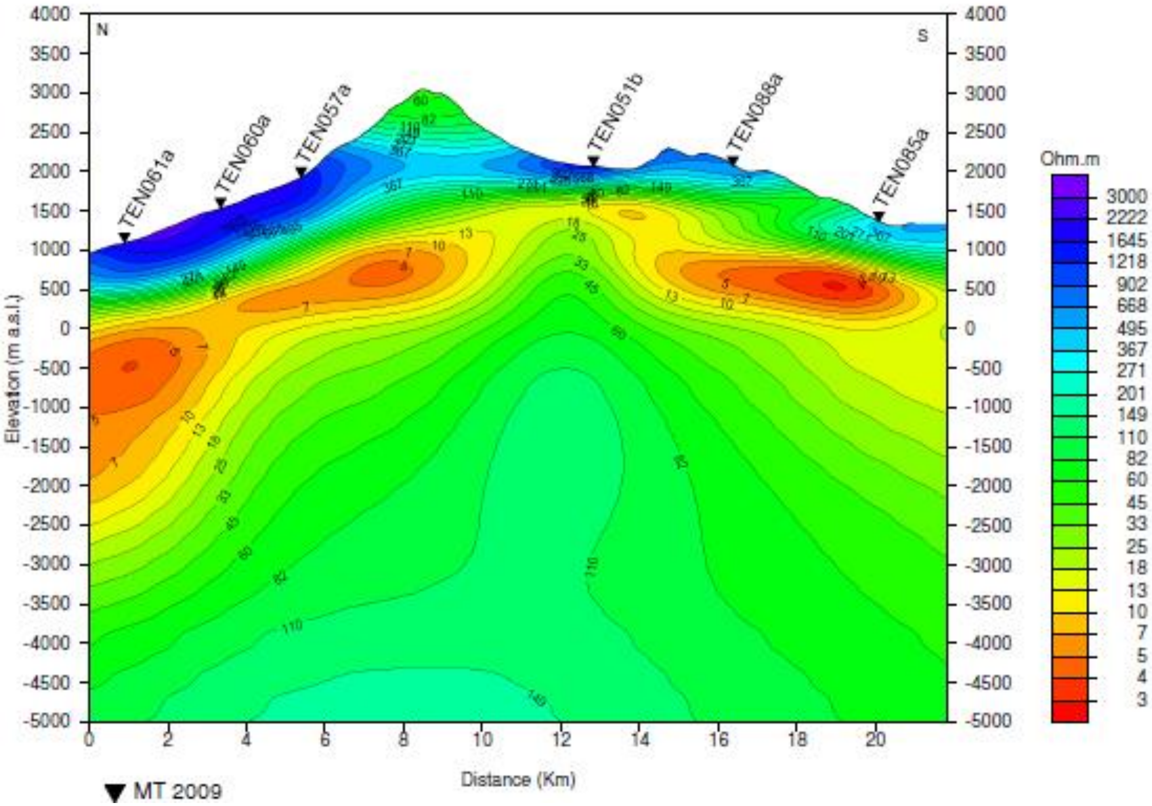
[a] Geochemical values from 1 (best value) to 5 (worst value)

Geothermal Exploration Research in the Canary islands

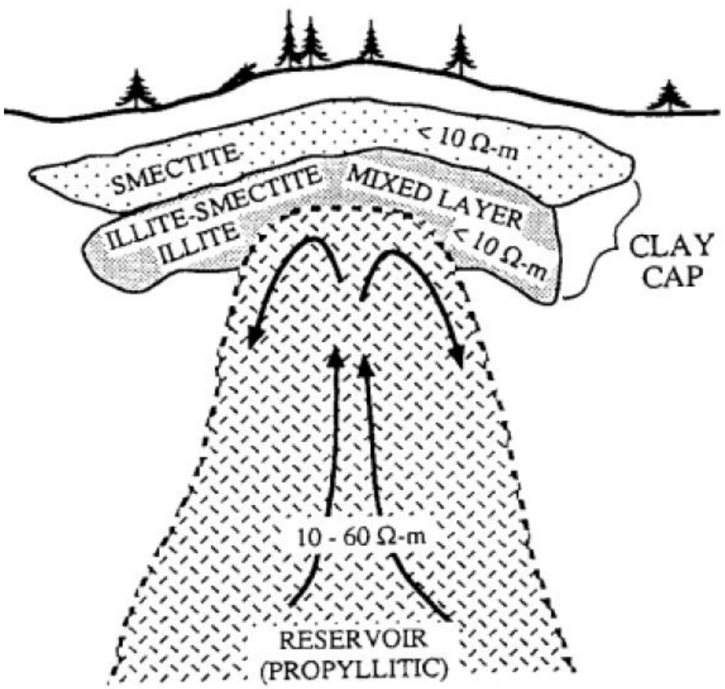


Geophysical methods for geothermal exploration (magnetotelluric)

Geothermal Exploration Research in the Canary islands

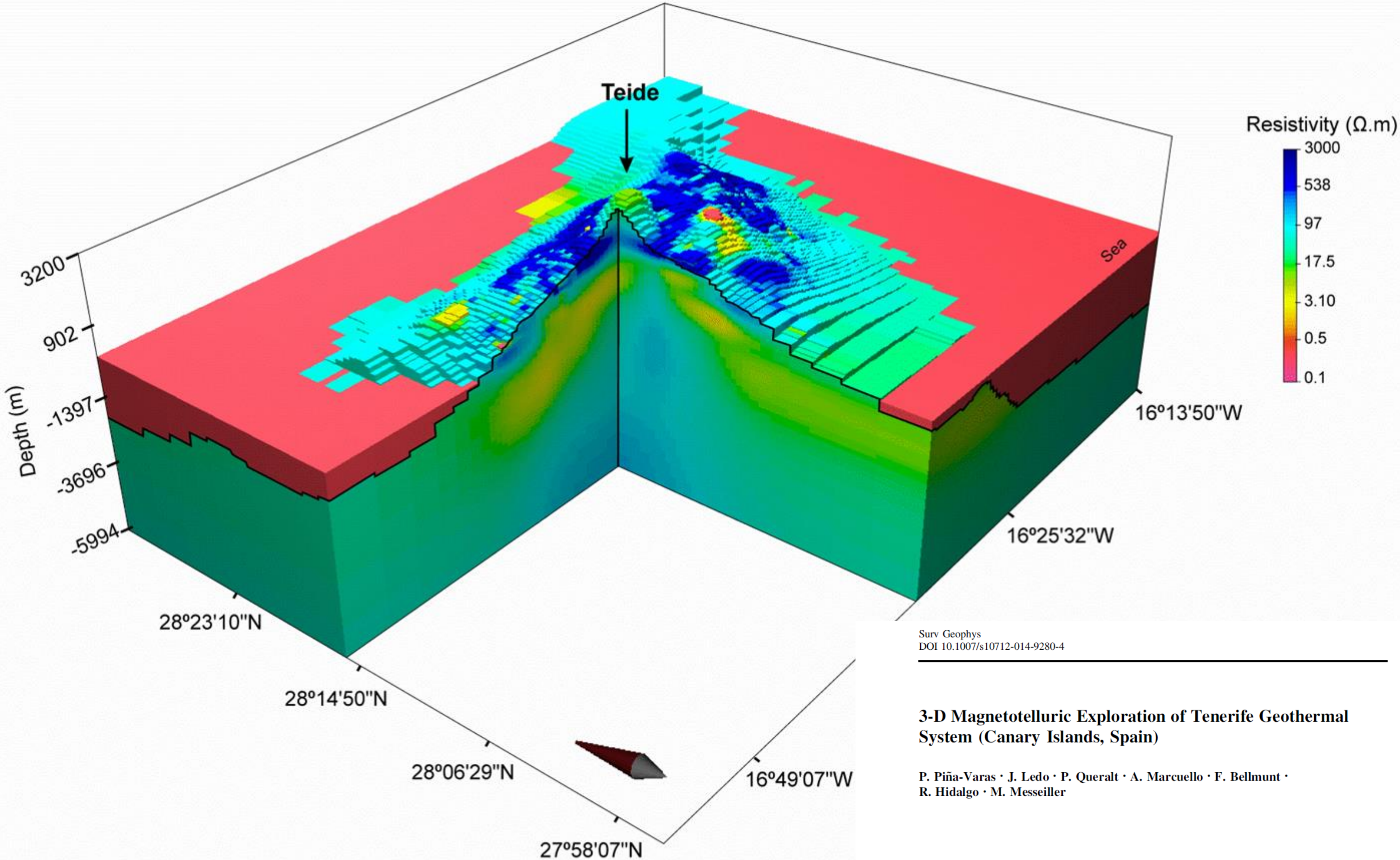


Métodos geofísicos para la exploración geotérmica (Métodos eléctricos, MT)



Geophysical methods for geothermal exploration (Electrical Methods, MT)

Geothermal Exploration Research in the Canary islands



Geophysical methods for geothermal exploration (MT)

Surv Geophys
DOI 10.1007/s10712-014-9280-4

3-D Magnetotelluric Exploration of Tenerife Geothermal System (Canary Islands, Spain)

P. Piña-Varas · J. Ledo · P. Queralt · A. Marcuello · F. Bellmunt · R. Hidalgo · M. Messeiller

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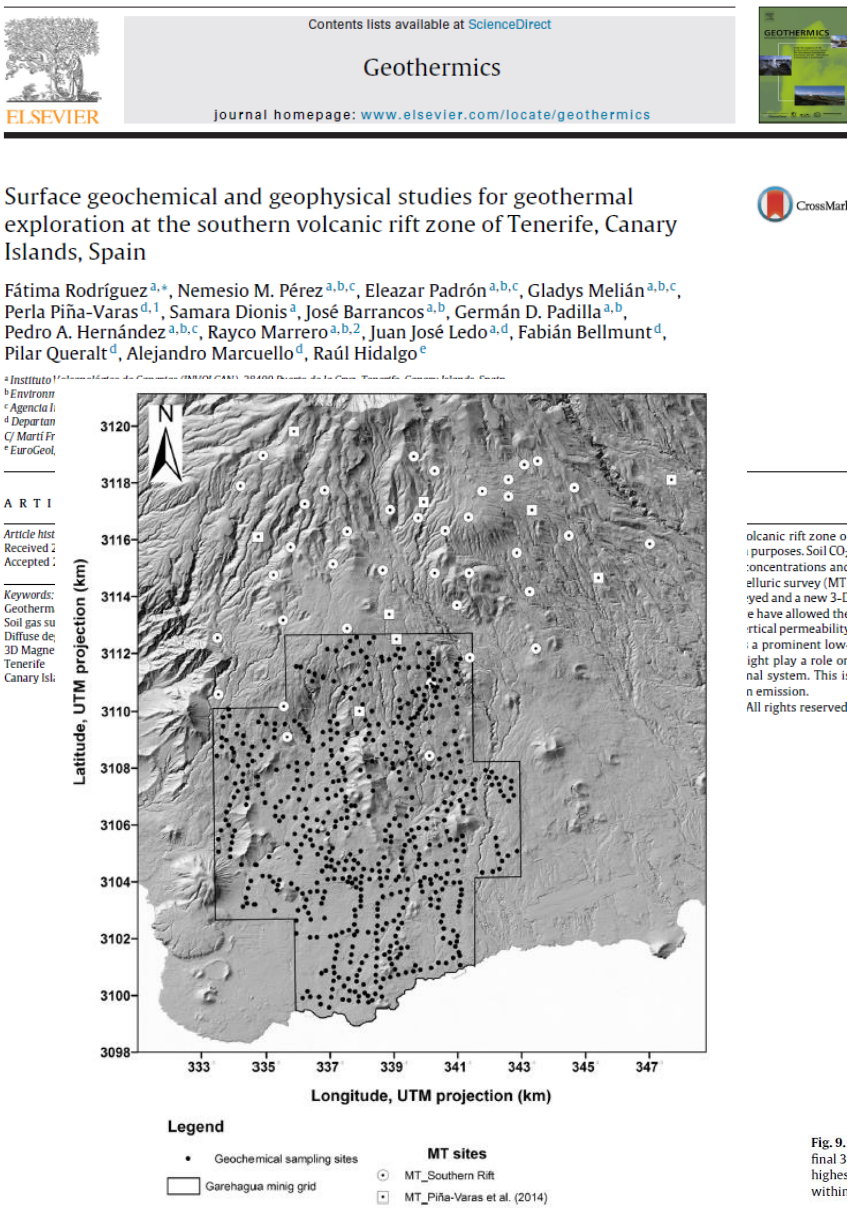
Abstract The resistivity structure of the Tenerife geothermal system has been deter-

Geothermal Exploration Research in the Canary islands



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journal homepage: www.elsevier.com/locate/geothermics

Surface geochemical and geophysical studies for geothermal exploration at the southern volcanic rift zone of Tenerife, Canary Islands, Spain

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...olcanic rift zone of ... purposes. Soil CO_2 ... concentrations and ... elluric survey (MT) ... yed and a new 3-D ... e have allowed the ... rtical permeability ... a prominent low- ... ight play a role on ... nal system. This is ... n emission.

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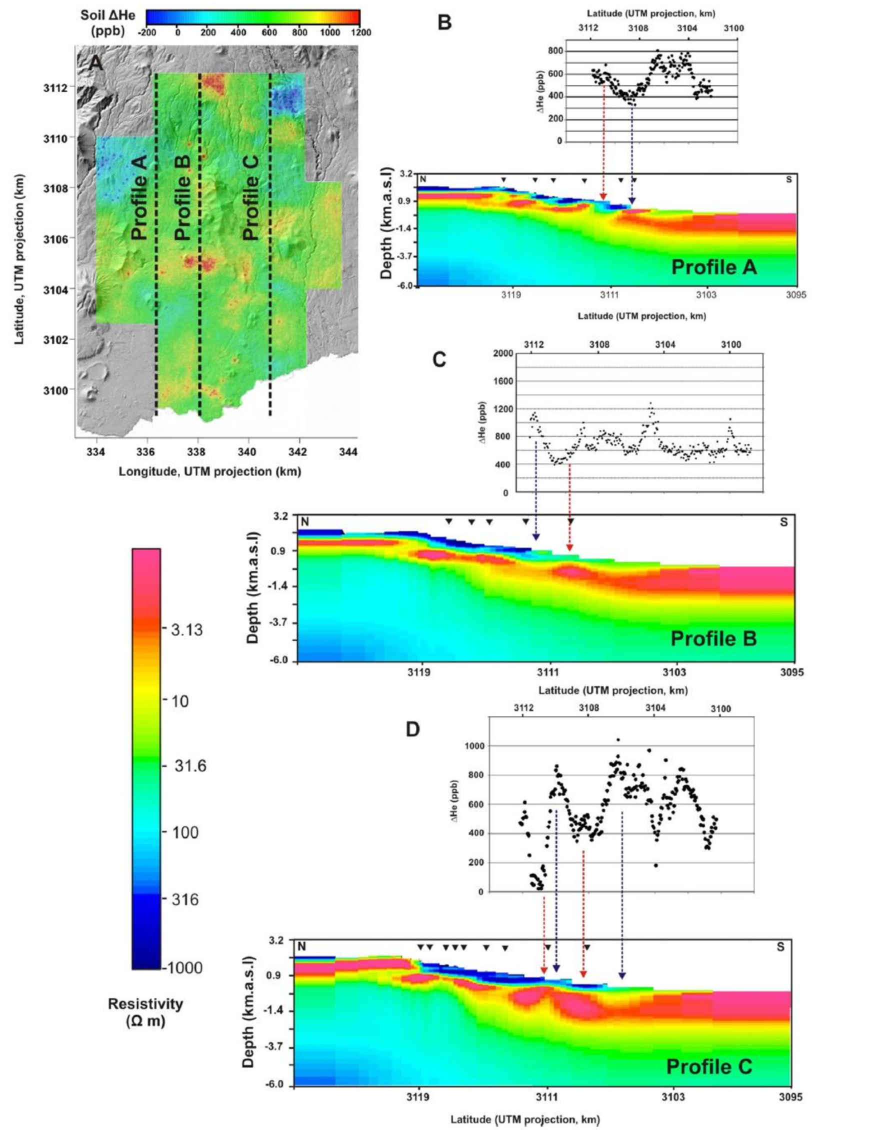
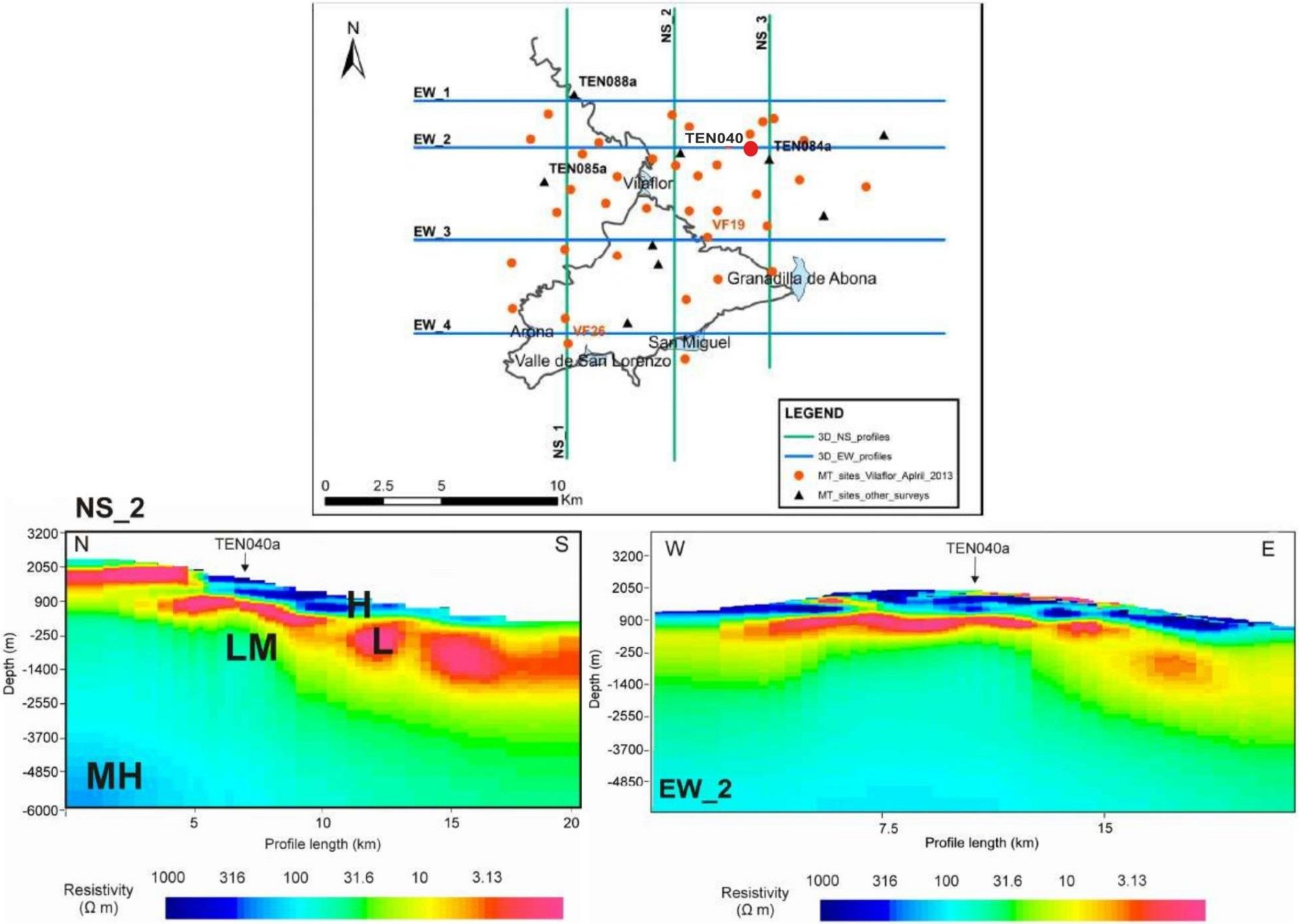


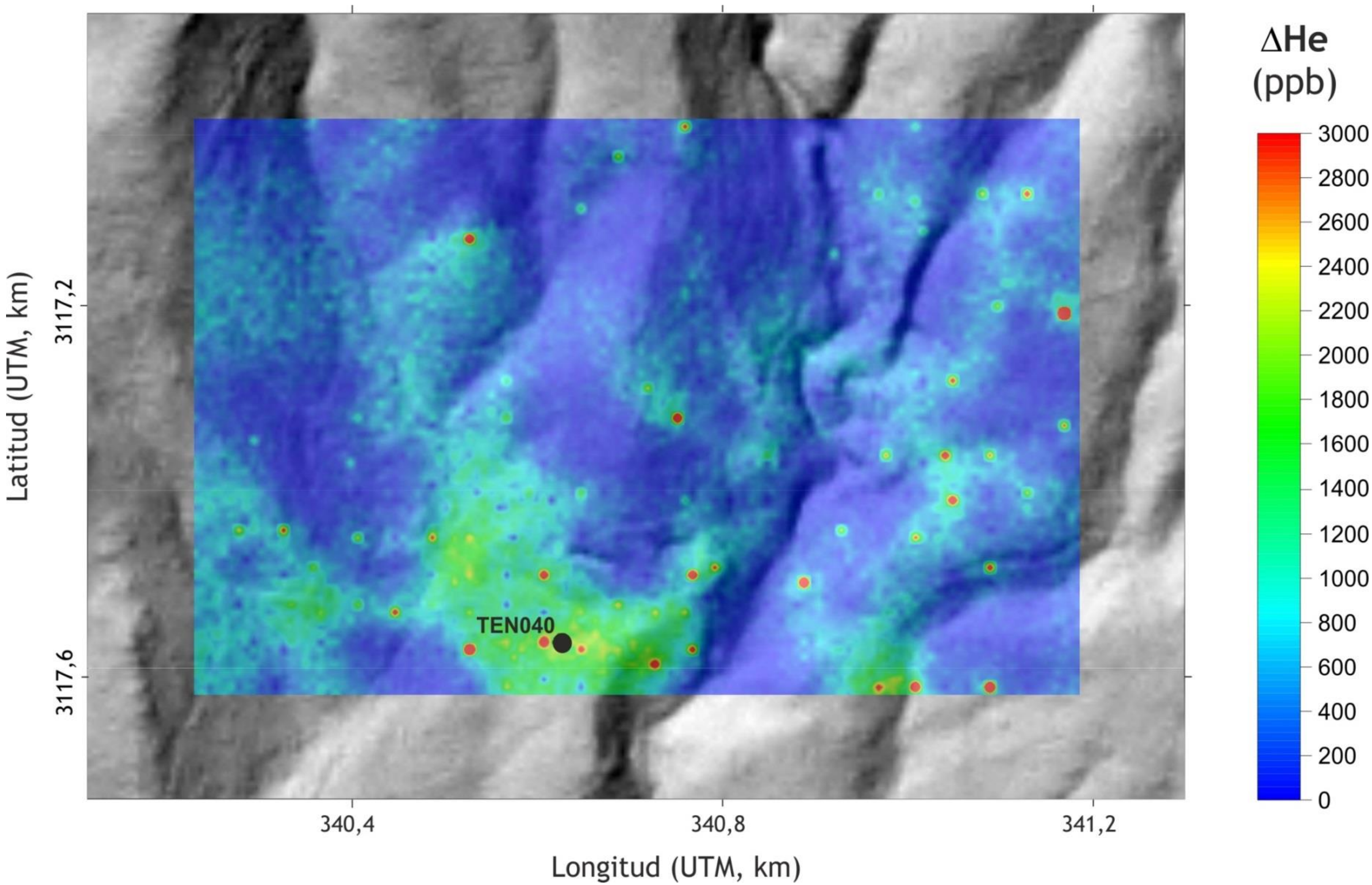
Fig. 9. (A) ΔHe map showing the location of the N–S resistivity cross-section corresponding to three N–S profiles. (B), (C) and (D) depict values of soil ΔHe and results of the final 3-D resistivity model along A, B and C vertical N–S cross-sections respectively. Blue and red dashed arrows indicate observed positive and negative correlation between highest values of ΔHe and clay cap discontinuities and lowest values of ΔHe and the thicker clay cap, respectively. Inverse black triangles show the location of MT sites within each profile. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

Geothermal Exploration Research in the Canary islands



Geothermal Exploration Research in the Canary islands

Spatial distribution of He enrichment ($\Delta He = He_{soil\ gas} - He_{air}$) in the soil gas atmosphere at the Madre del Agua study area



Economic model developed by Petratherm-Hispania

Assumption	Value
Temperature	240ºC
Flow Rate	100 l/s
Net Well output	7.8 MW/well
Production : Injection Ratio	2:1
Drilling Cost per well	€5 - 6m
CAPEX Plant and above ground 28 MW	€1.23M/MW

Base Case Capital Requirements	28 MW Development
Total Wells	**7**
Drilling Capital	**€42m**
Above Ground & Plant Capital	**€38.26m**
Transmission Capital	**€20m**
Civils and roads	**€5m**
2 Make up wells	**€10m**
Total Capital	**€115.26m**

Electricity Price	IRR
90€/MWh	**15.1%**
125€/MWh	**20.4%**
150€/MWh	**24.0%**

Geothermal Development at other oceanic volcanic islands

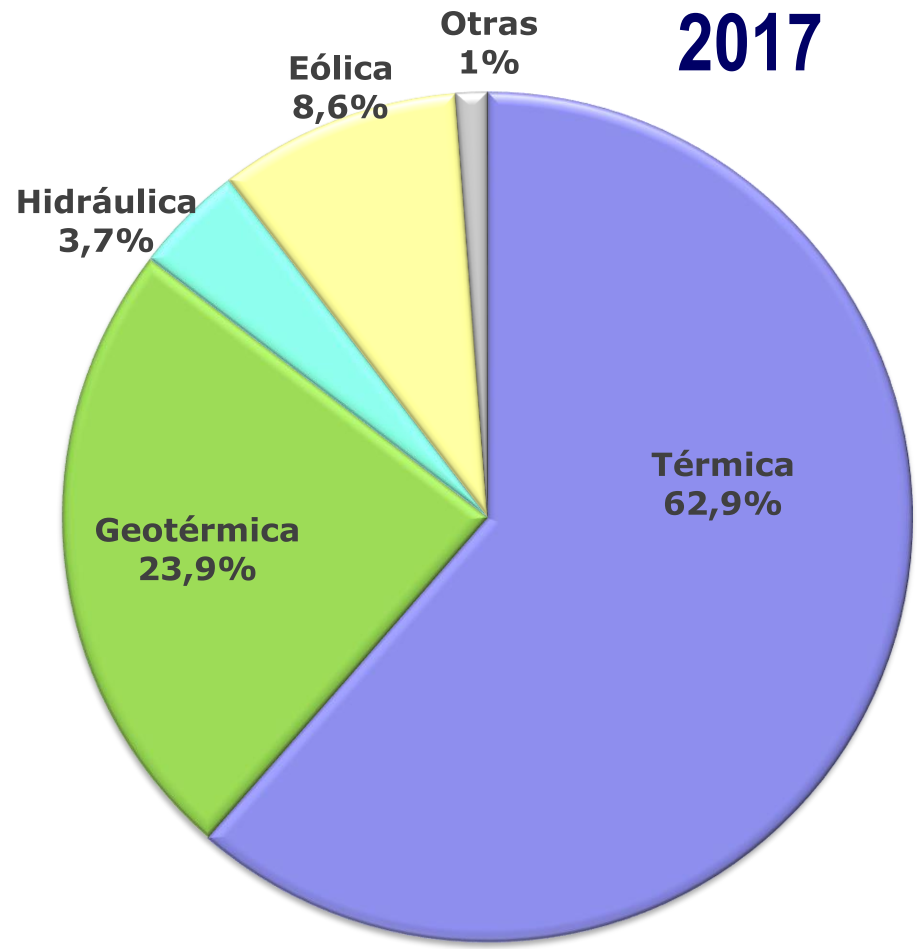
Ribera Grande Geothermal Power Plant, São Miguel, Azores

Geothermal Development at other oceanic volcanic islands

AZORES · Electricity Production

EDA RENOVÁVEIS
GRUPO EDA

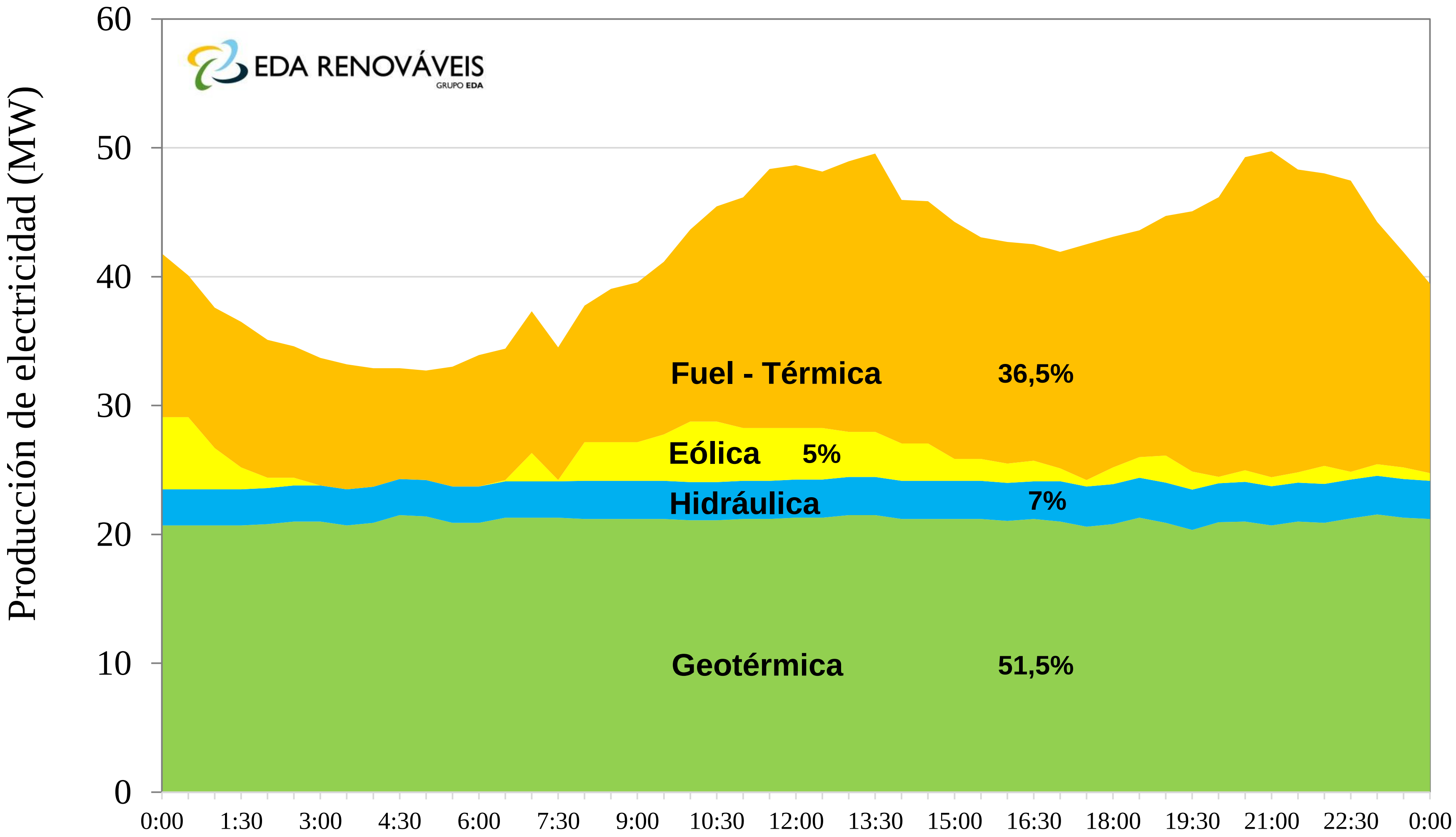
	Potência (MW)	Produccion (GWh)
Geotérmica	27	190,3
Residuos	3	7,0
Hidráulica	9	29,3
Termica	219	500,4
Eólica	29	68,1
Total	**286**	**795,2**



Geothermal Development at other oceanic volcanic islands

São Miguel (Azores, Portugal) – Electricity production graph

April 2, 2017



Key Messages about Geothermal

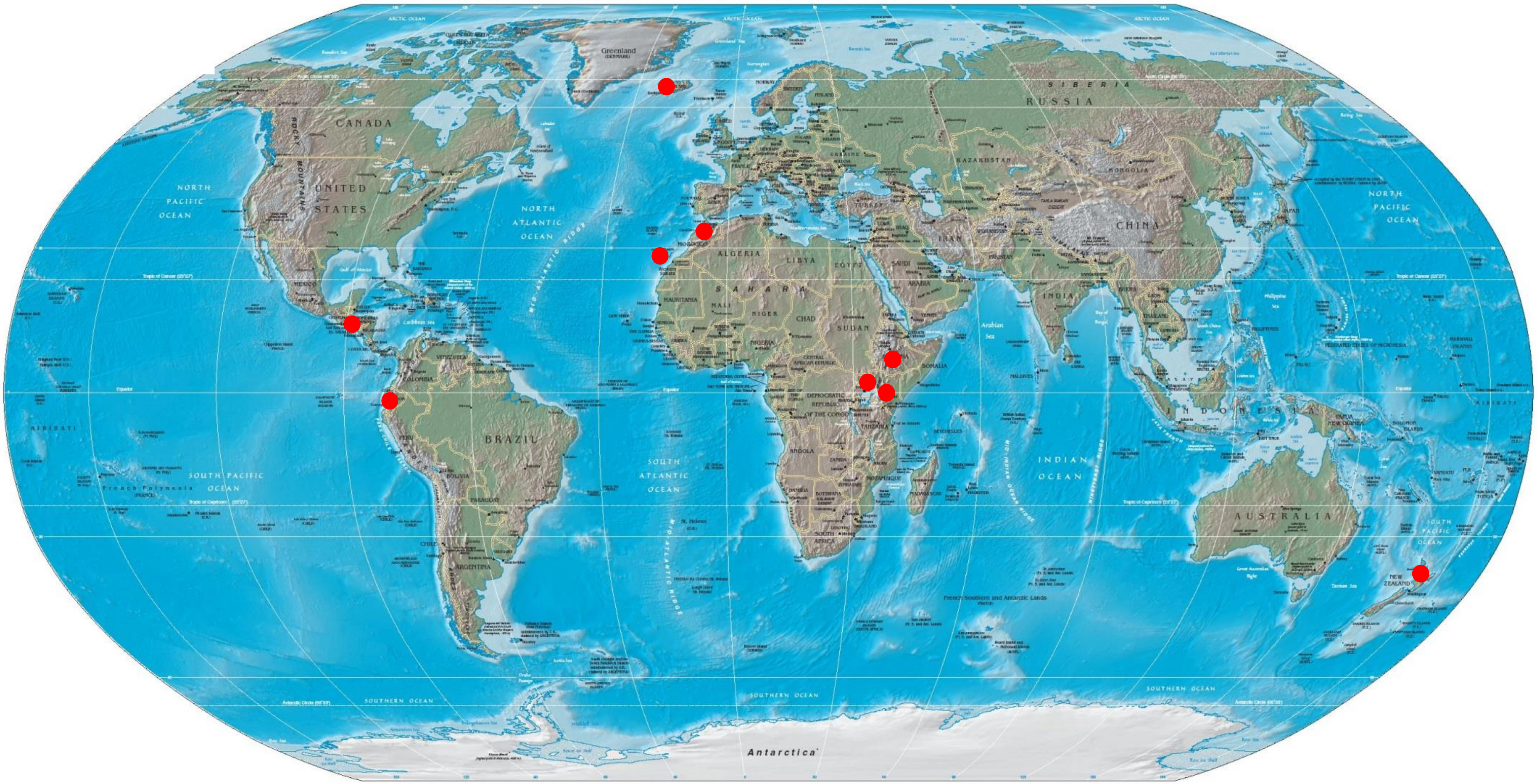
- RESOURCE POTENTIAL: Geothermal is a widely available energy source, since underground heat is available everywhere. Is renewable and suistanable.
- STABILITY & AVAILABILITY: Geothermal energy is available around the clock and has a predictable output.
- FLEXIBILITY: Geothermal operates continuously to meet the minimum level of power demand and may adapt to meet variable levels of energy demand.
- GROWTH: Production from untapped geothermal resources has the potential to become a local economic development booster.
- OPTIMISATION: Geothermal is a versatile energy, whose multiple-applications are optimised by cascading uses of heat at progressively lower temperatures
- SUSTAINABILITY: The geothermal environmental footprint is much lower than those of other energy sources.

Conclusions

- ✓ Tenerife has great potential to host high enthalpy geothermal resources.
- ✓ Tenerife also has an important and stable energy demand supported by the consumption of the resident and tourism populations.
- ✓ The energy isolation of the islands makes it a very unique market with average electricity prices close to 150 €/MWh . Geothermal energy can provide stability to the grid, contribute to the reduction of fossil fuels and emissions and reduce the average price of energy.
- ✓ Tenerife's future energy goes through the development of high enthalpy geothermal energy.
- ✓ Tenerife Geothermal Power Project is actually in an advanced phase of surface geothermal exploration.
- ✓ Investors and technological partners are welcome to join to the Tenerife Geothermal Power Project which main purpose is the generation of electricity through geothermal resources.

INVOLCAN Geothermal Exploration Research Program

Programa de Investigación sobre Exploración Geotérmica del INVOLCAN



Canary Islands, Ecuador, El Salvador, Ethiopia, Iceland, Kenya, Morrocco, New Zeland & Rwanda

Canarias, Ecuador, El Salvador, Etiopía, Islandia, Kenia, Marruecos, Nueva Zelanda, y Ruanda

Potential new uses of geothermal resources

ELMOTOR   EL PAÍS as CincoDías

ACTUALIDAD PRUEBAS SUPERCOCHES TECNOLOGÍA ELÉCTRICOS CONDUCIR MOTOS FICHAS Y PRECIOS

Vulcanol, el combustible que sale directamente de los volcanes

La multinacional china Geely, empresa matriz de Volvo, está haciendo pruebas con un combustible extraído de la actividad volcánica

Luis A. Soto · 08/03/2018 ❤ 5

La berlina Emgrand 7 utilizada en las pruebas de Geely.