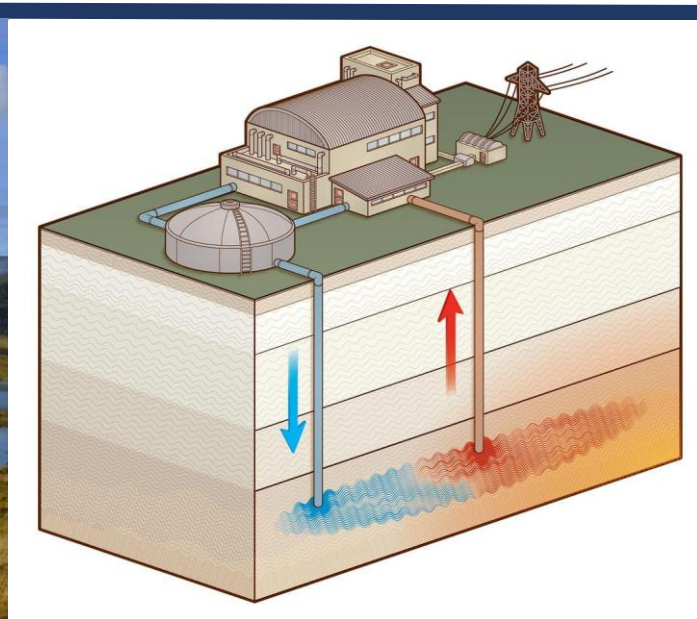
INSTITUTO DE ENERGIA E AMBIENTE
UNIVERSIDADE DE SÃO PAULO

# Energia Geotérmica:
# usinas em operação e potenciais no mundo, ALC e Brasil

**Mestrando:** Rodrigo Mota Rodi
**Disciplina:** PEN5002 – Recursos e Oferta de Energia
**Docentes Responsáveis:** Célio Bermann e Virginia Parente



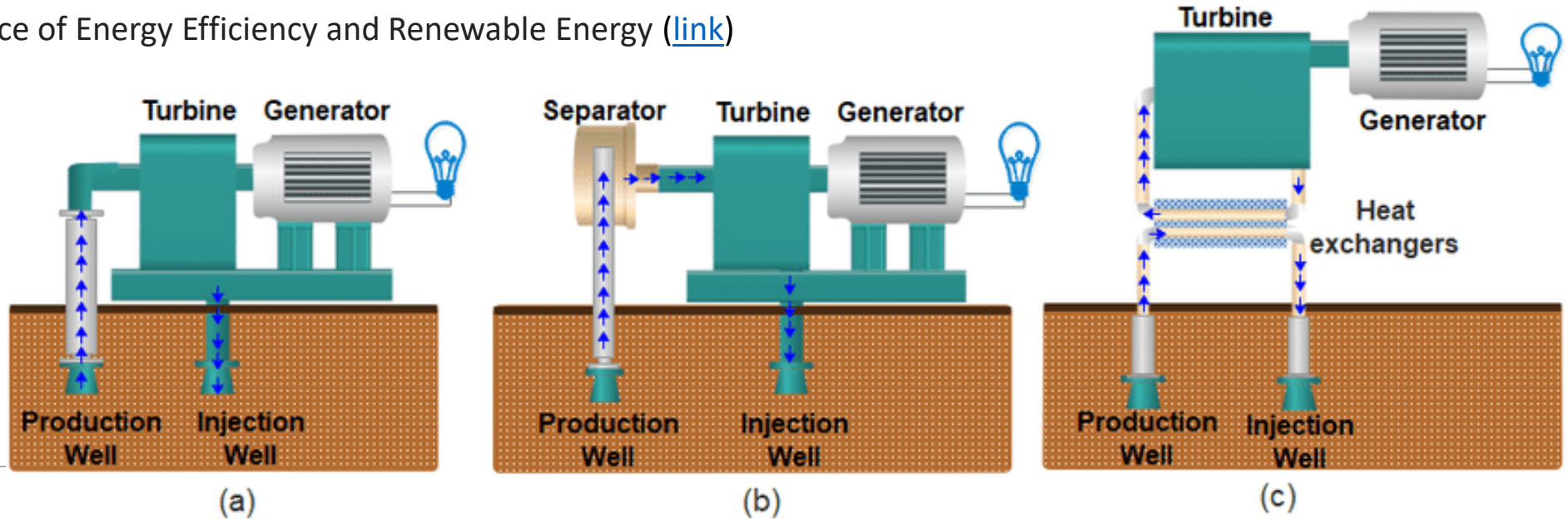
# Introdução: Processo de conversão energética

**a) Vapor seco** utilizam vapor direto de um reservatório geotérmico para alimentar turbinas e gerar eletricidade; mais conveniente;

**b) Vapor úmido** convertem a água quente de alta pressão profundas em vapor, que, quando esfria, se condensa; a água e é injetada de volta no solo para ser usada novamente; sistema mais abundante.

**c) Ciclo binário** transferem o calor da água quente geotérmica para outro líquido, que se transforma em vapor usado para acionar uma turbina de gerador.

Fonte: EERE - Office of Energy Efficiency and Renewable Energy (link)



# Dados Mundiais


Fonte: International Geothermal Association – IGA. https://www.geothermal-energy.org/explore/our-databases/geothermal-power-database/ Created with mapchart.net ©

Global Geothermal Use 2015

**Total em 2015: 12.636,10 MW de capacidade de geração de eletricidade instalada**

| COUNTRY | 1990 MWE | 1995 MWE | 2000 MWE | 2005 MWE | 2010 MWE | 2013 MWE | 2015 MWE |
|---|---|---|---|---|---|---|---|
| USA | 2.774,6 | 2.816,7 | 2.228,0 | 2.544,0 | 3.093,0 | 3.389,0 | 3.450,0 |
| Philippines | 891,0 | 1.227,0 | 1.909,0 | 1.931,0 | 1.904,0 | 1.848,0 | 1.870,0 |
| Indonesia | 144,8 | 309,8 | 589,5 | 797,0 | 1.197,0 | 1.341,0 | 1.340,0 |
| Mexico | 700,0 | 753,0 | 755,0 | 953,0 | 958,0 | 1.017,4 | 1.017,0 |
| New Zealand | 283,2 | 286,0 | 437,0 | 435,0 | 628,0 | 842,6 | 1.005,0 |
| Italy | 545,0 | 631,7 | 785,0 | 790,0 | 843,0 | 875,5 | 916,0 |
| Iceland | 44,6 | 50,0 | 170,0 | 322,0 | 575,0 | 664,4 | 665,0 |
| Kenya | 45,0 | 45,0 | 45,0 | 127,0 | 167,0 | 248,5 | 594,0 |
| Japan | 214,6 | 413,7 | 546,9 | 535,0 | 536,0 | 537,0 | 519,0 |
| Turkey | 20,6 | 20,4 | 20,4 | 20,4 | 82,0 | 166,6 | 397,0 |
| Costa Rica | 0,0 | 55,0 | 142,5 | 163,0 | 166,0 | 207,1 | 207,0 |
| El Salvador | 95,0 | 105,0 | 161,0 | 151,0 | 204,0 | 204,4 | 204,0 |
| Nicaragua | 35,0 | 70,0 | 70,0 | 77,0 | 88,0 | 149,5 | 159,0 |

Fonte: International Geothermal Association – IGA (link).

# Mundo

*Figure 3: Global installed geothermal capacity*

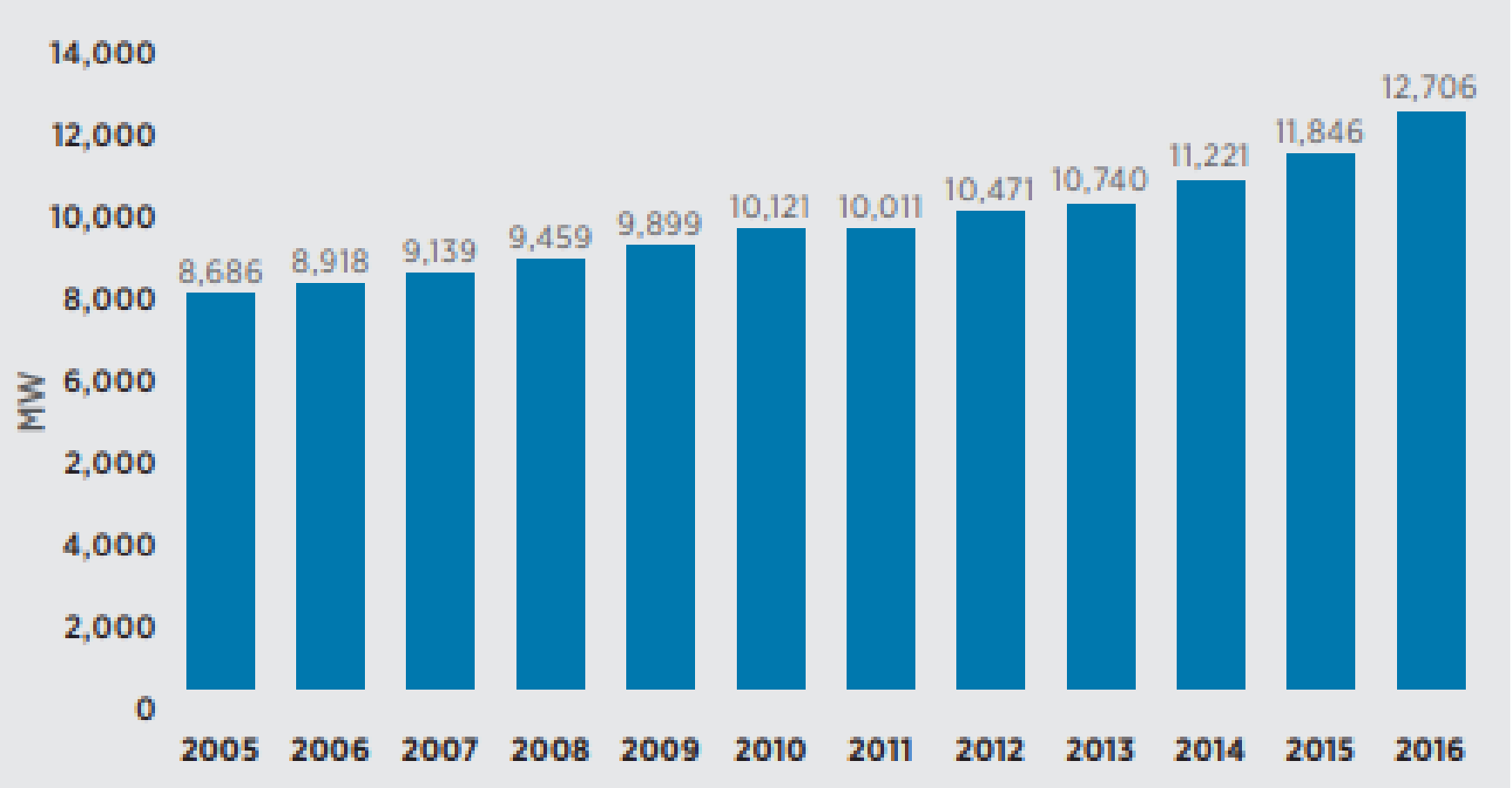



*Table 1: Net installed geothermal power capacity by country in 2016*

| Country | Capacity (MW) |
|---|---|
| USA | 2 511 |
| Philippines | 1 916 |
| Indonesia | 1 534 |
| Kenya | 1 116 |
| New Zealand | 986 |
| Mexico | 951 |
| Italy | 824 |
| Turkey | 821 |
| Iceland | 665 |
| Japan | 533 |
| Costa Rica | 207 |
| El Salvador | 204 |
| Nicaragua | 155 |
| Russian Federation | 78 |
| Papua New Guinea | 53 |

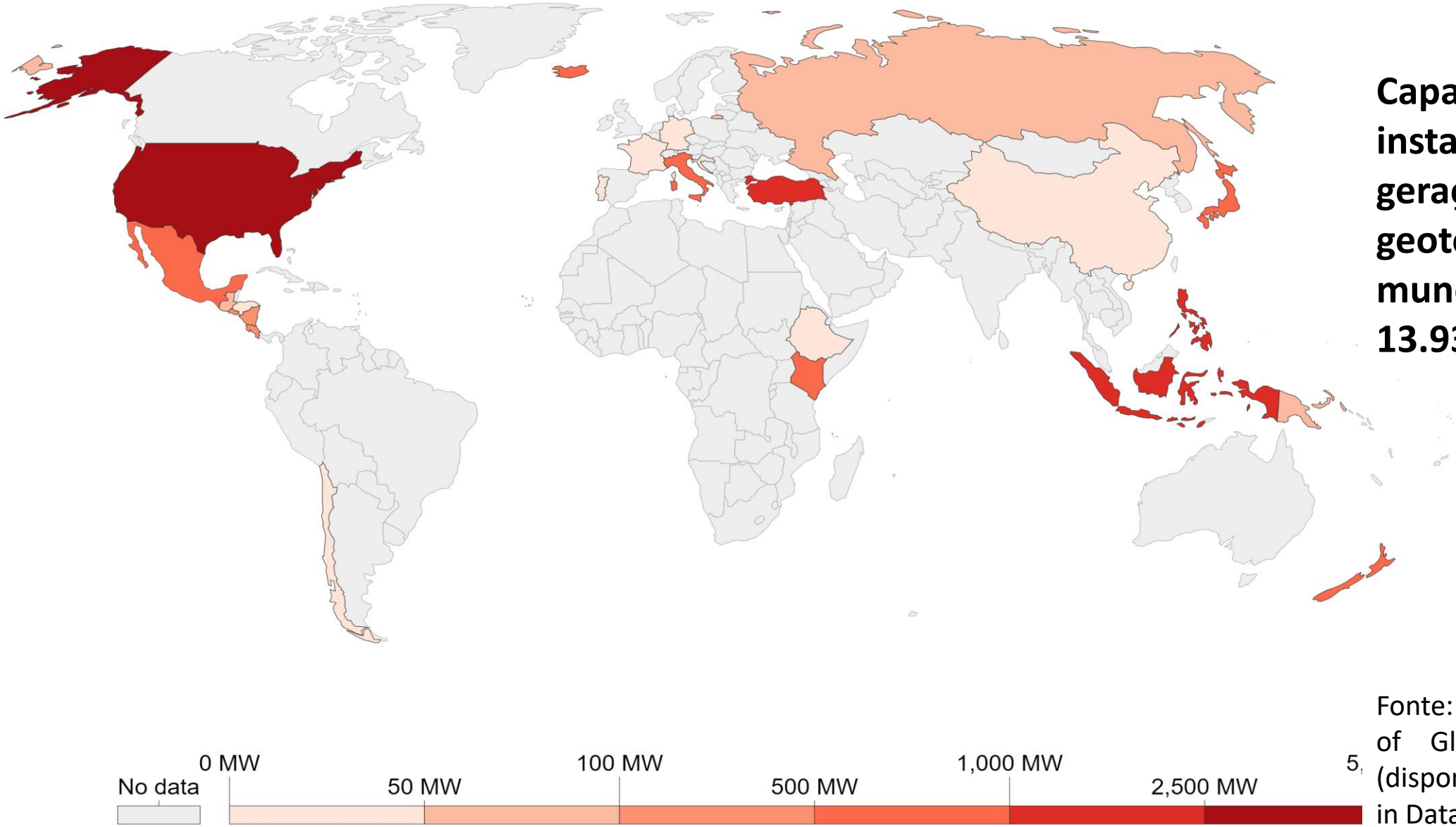
*Source: IRENA, 2017a*

Fonte: IRENA (2017), Geothermal Power: Technology Brief, International Renewable Energy Agency, Abu Dhabi (link) e IRENA (2017a). “Featured Dashboard – Capacity Generation” (link)

# Installed geothermal energy capacity, 2019

Cumulative installed capacity of geothermal energy, measured in megawatts.

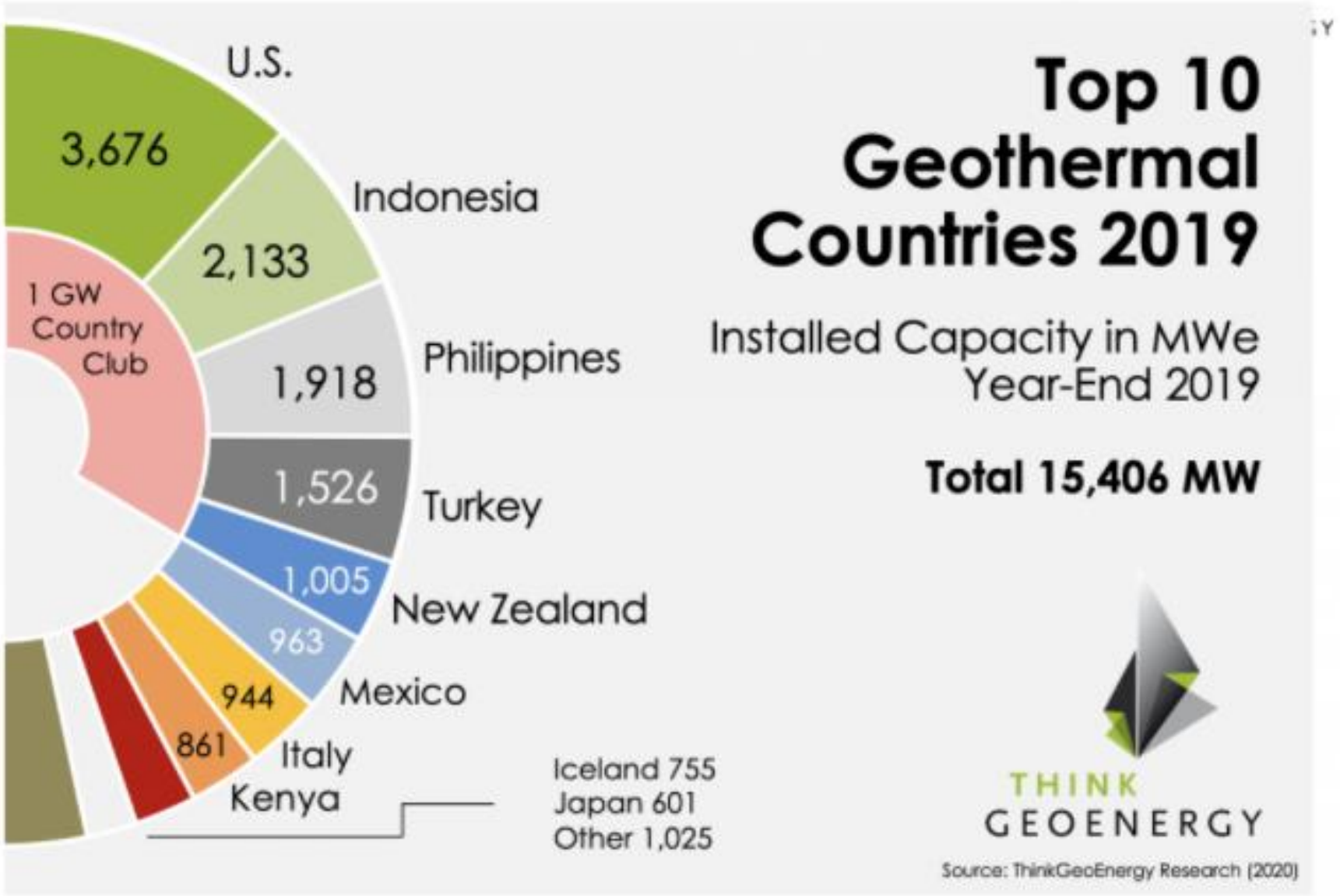
Our World in Data




**Capacidade instalada de geração geotérmica mundial em 2019: 13.930,58 MW**

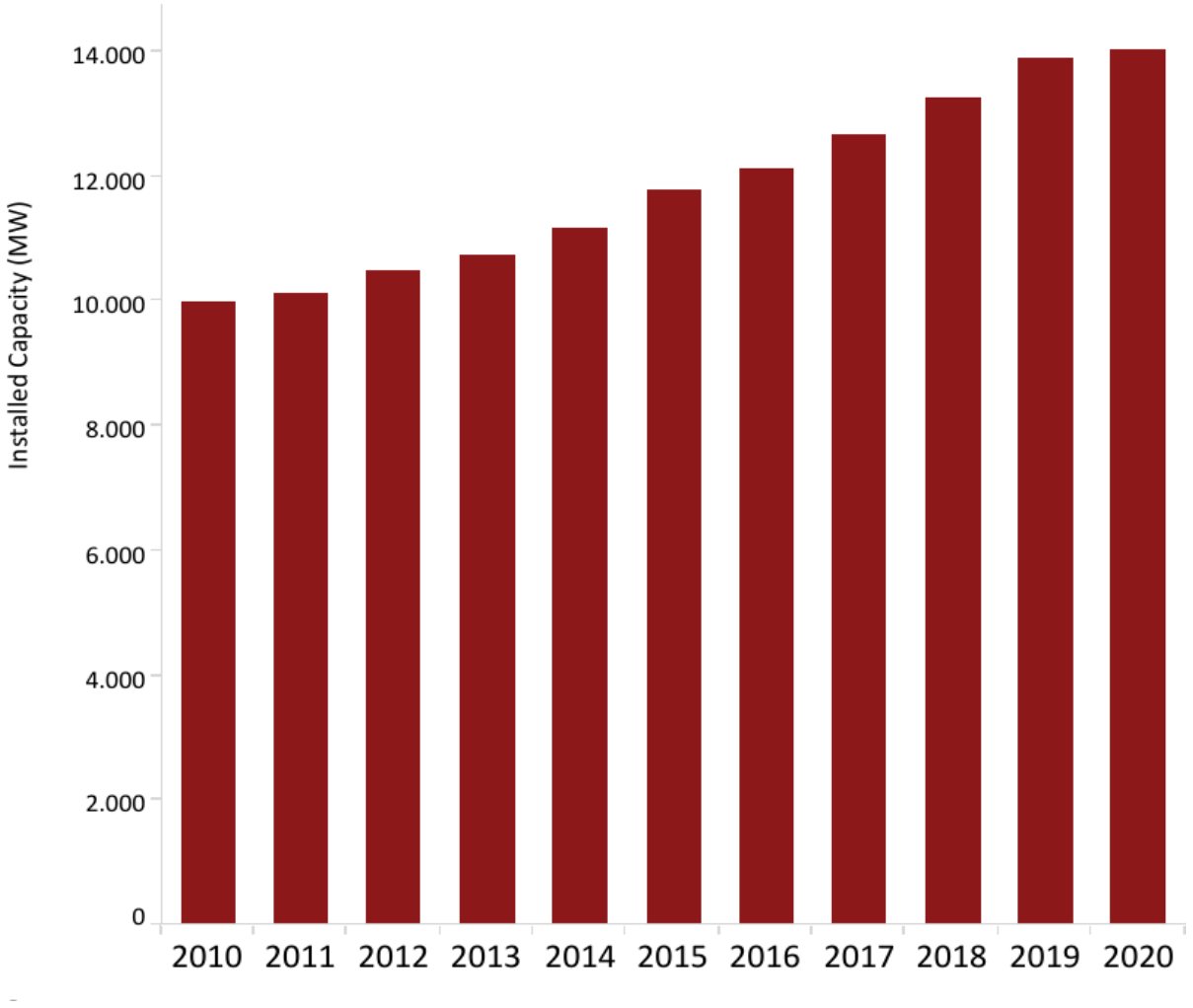
Fonte: BP Statistical Review of Global Energy, 2020 (disponível em: Our World in Data link)

# The Top 10 Geothermal Countries 2019 – based on installed generation capacity (MWe)

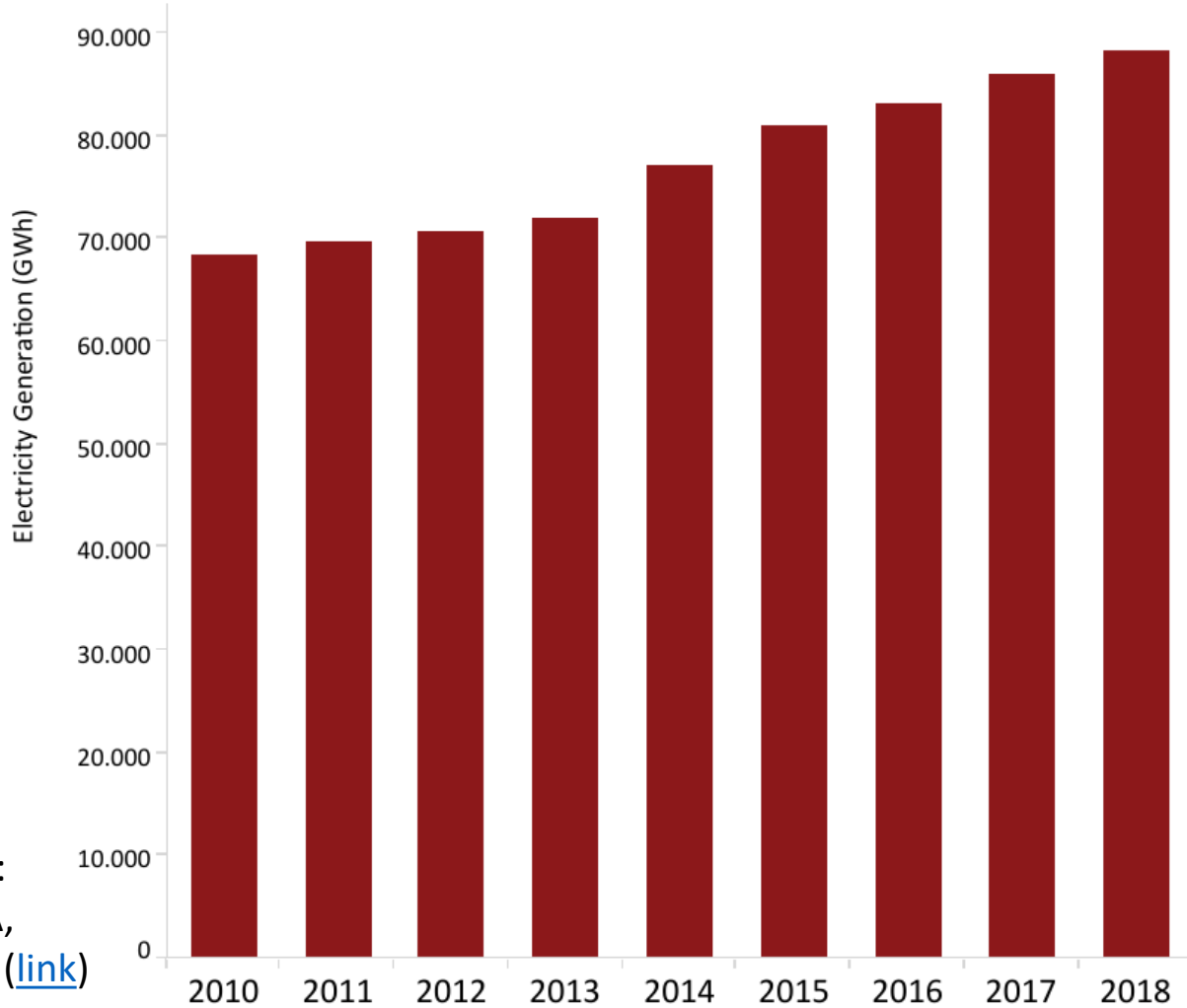



Fonte: Think Geo Energy (link)

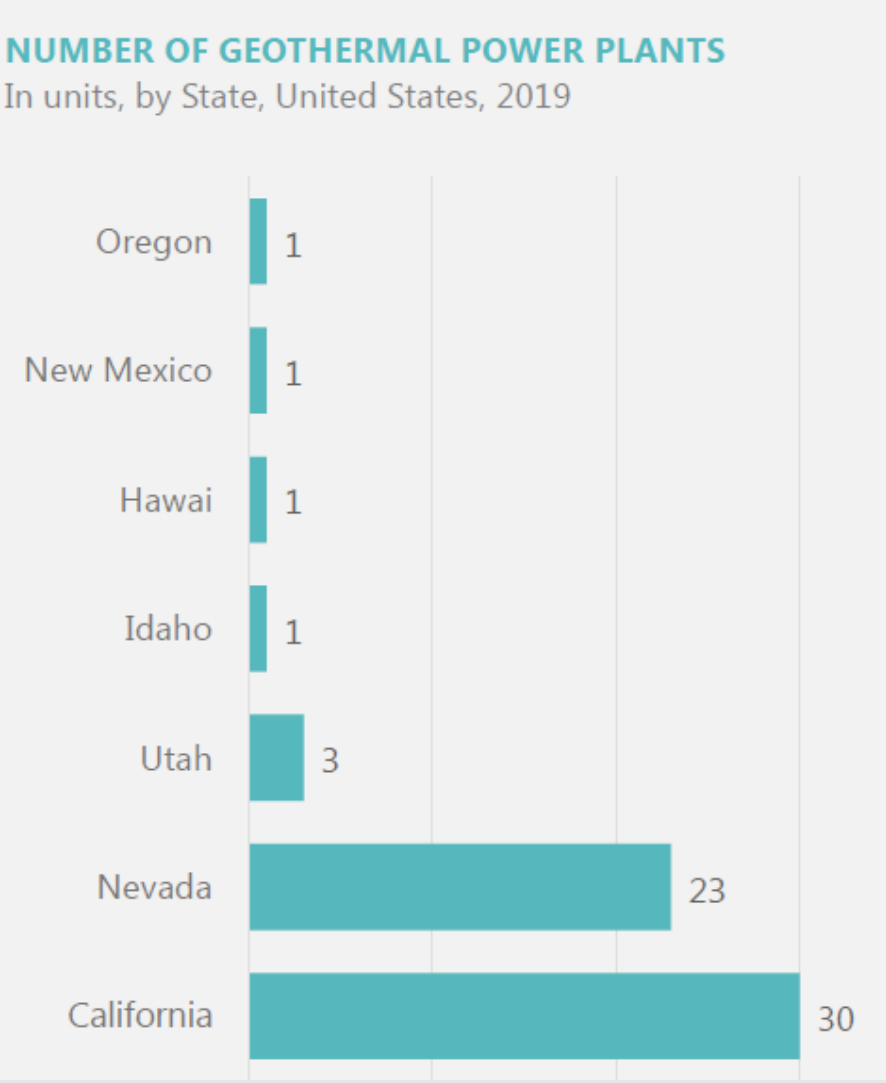
# Mundo



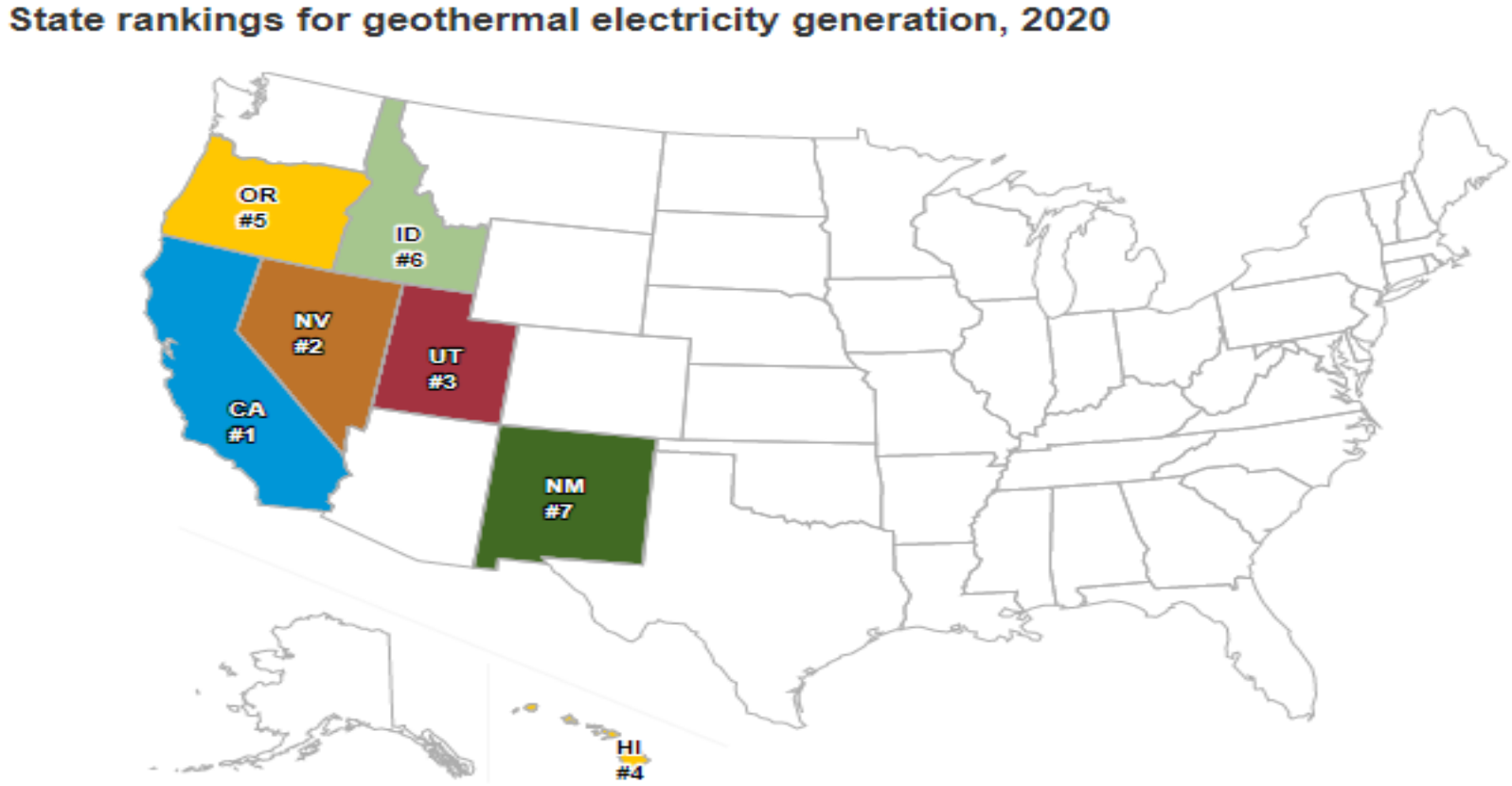

Fonte: IRENA, 2021. (link)



# EUA




Fonte: US Energy Information Administration (link)



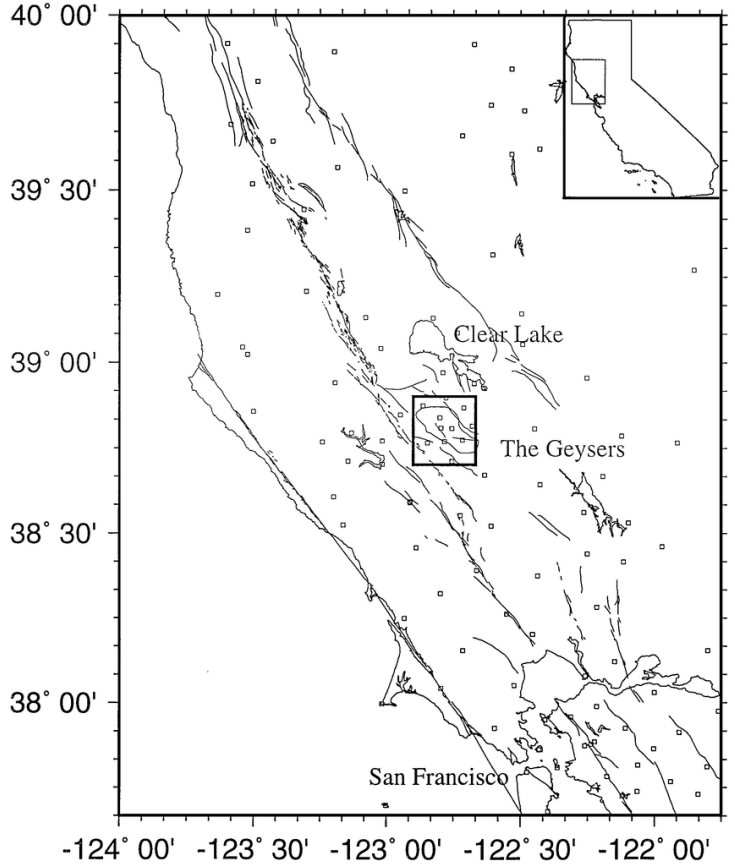

**States with geothermal power plants in 2020**

| | State share of total U.S. geothermal electricity generation | Geothermal share of total state electricity generation |
|---|---|---|
| California | 70.5% | 6.1% |
| Nevada | 24.5% | 10.2% |
| Utah | 2.1% | 1.0% |
| Hawaii | 1.2% | 2.2% |
| Oregon | 0.9% | 0.2% |
| Idaho | 0.5% | 0.5% |
| New Mexico | 0.3% | 0.2% |

# Mundo: maiores usinas

## The Geysers, Califórnia, EUA

- Vapor seco
- Capacidade instalada de 1.590 MW
- Mais antiga dos EUA (1920)




Fonte: ROSS, A; FOULGER, G. R.; JULIAN, B. R. Source processes of industrially-induced earthquakes at The Geysers geothermal area, California. *Geophysics*, v. 64, n. 6 (nov-dez), 1999, p. 1878.

# Mundo: maiores usinas
## Cerro Prieto, México

- Vapor seco
- Capacidade instalada de 820 MW
- Mexicali, Baja California
- Maior aproveitamento geotérmico do país (75% capacidade geotérmica em operação)

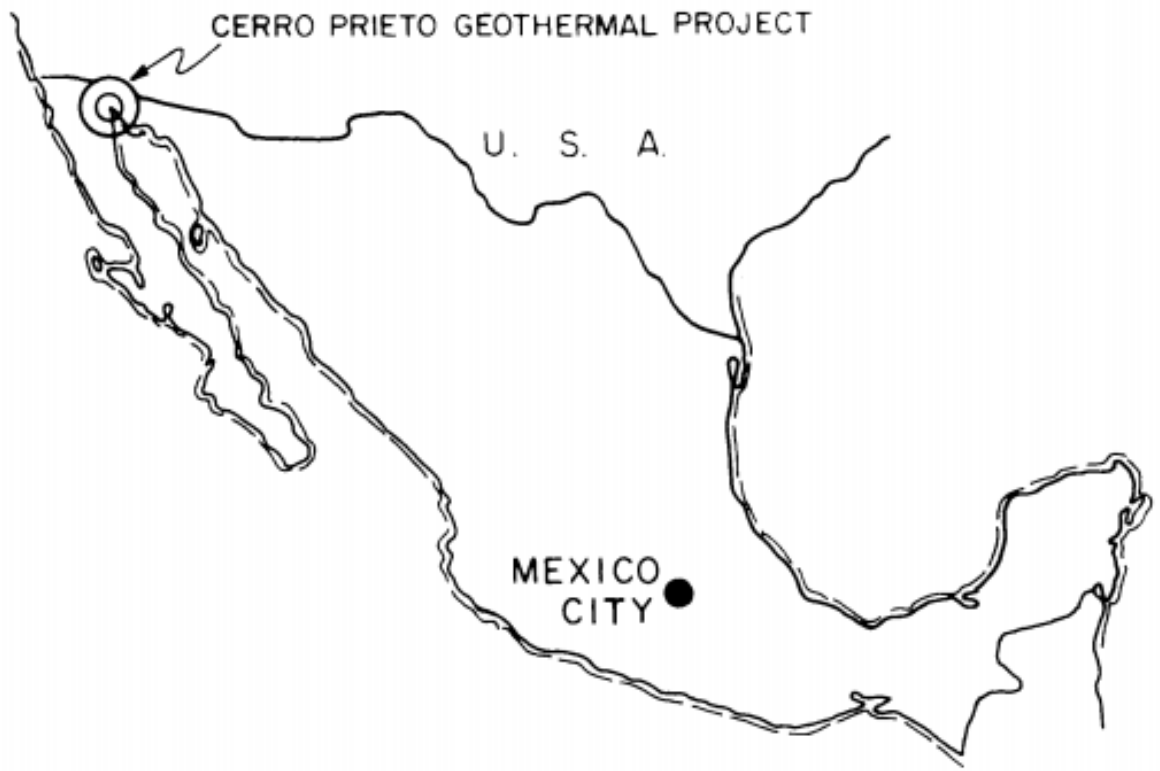
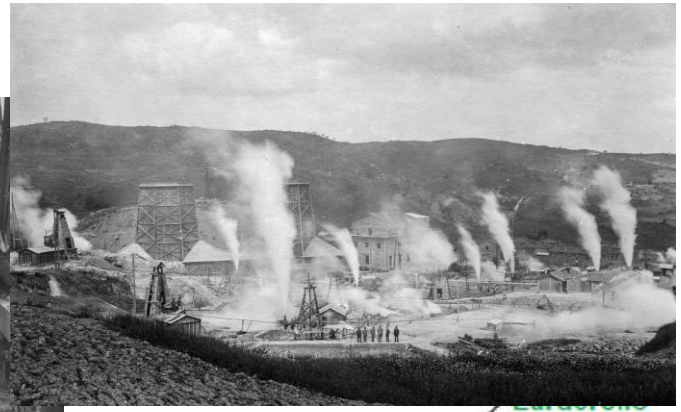


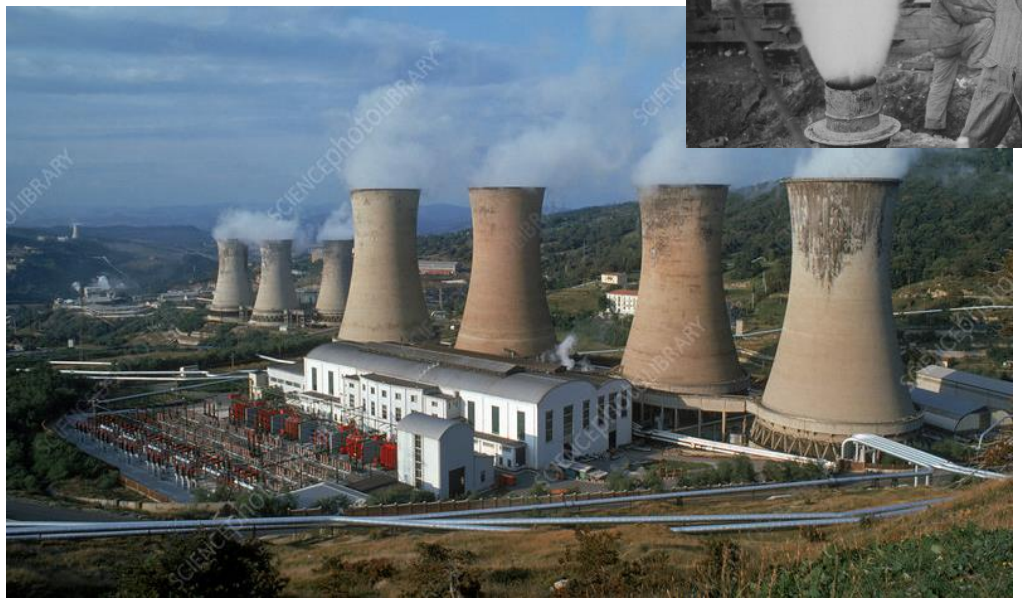

Fig. 7-1. Cerro Prieto geothermal field, Mexico.

Fonte: CFE (Comisión Federal de Electricidad). LIBRO BLANCO - Perforación de 30 pozos en el campo geotérmico de Cerro Prieto, B.C., 2012. (link)
PV Magazine. Mexican utility confirms first invesment in solar. (link)
GUPTA, Harsh K. Chapter 7 - The Cerro Prieto Geothermal Field, Mexico. Developments in Economic Geology, v. 12, 1980, p. 140.

# Mundo: maiores usinas
## Larderello, Itália

- Vapor seco
- Capacidade instalada de 769 MW
- Mais antiga do mundo (1913)





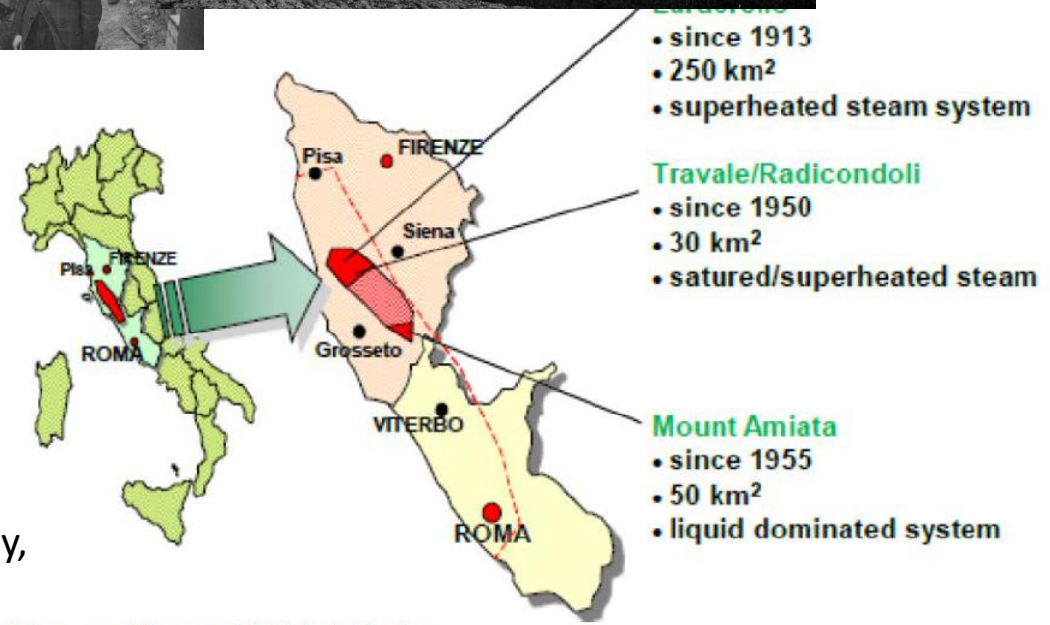
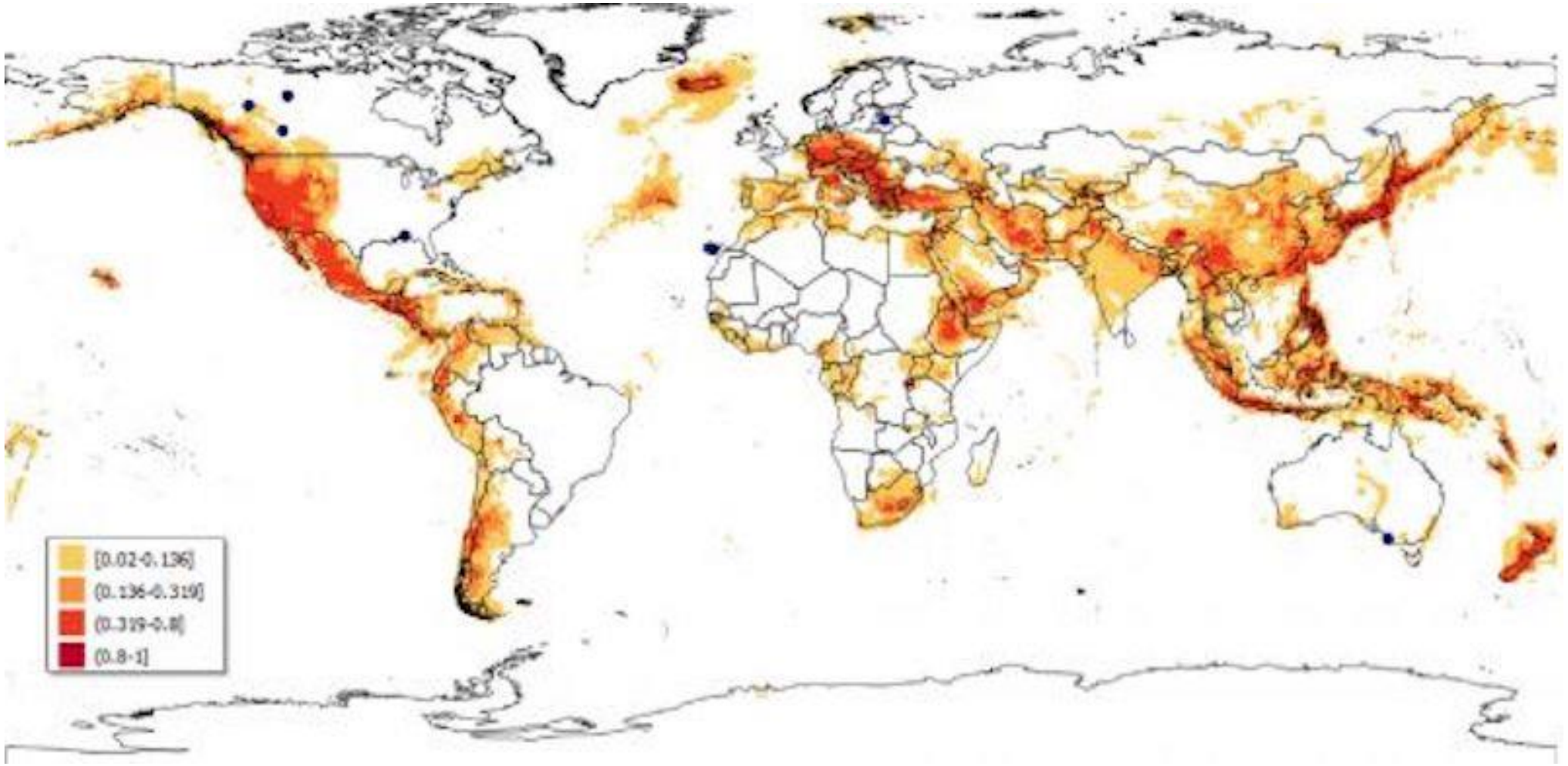


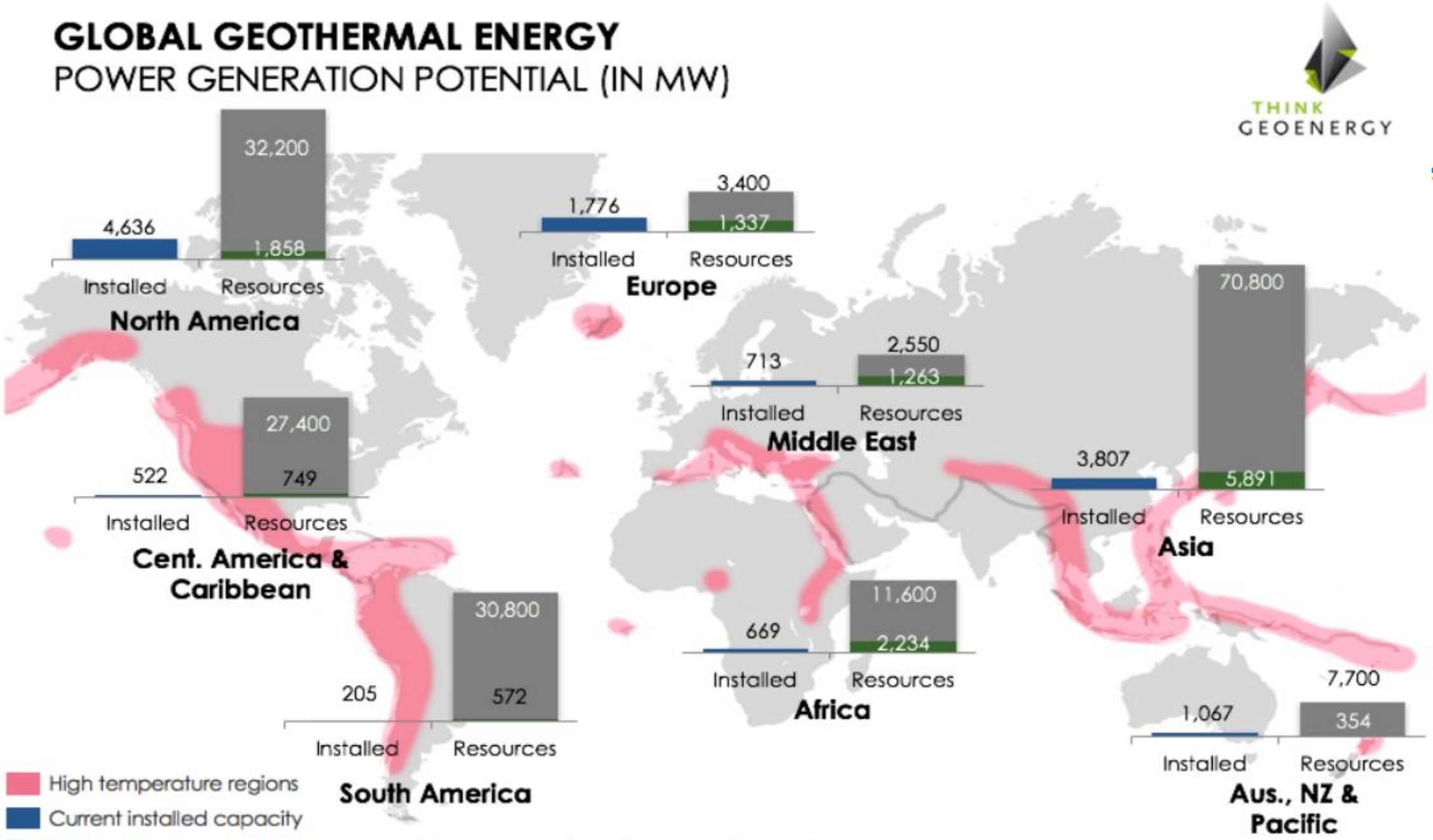

Figure 12-2: location of the geothermal fields in Italy

Fonte: UNWIN, Jack. “The oldest geothermal plant in the world”. Power Technology, outubro 2019. (link) e Enel Green Power . Geothermal Energy. (hlink e link)

# Mundo: Potencial




Fonte: Institute of Geosciences and Earth Resources (Instituto di Geoscienze e Georisorse - IGG) of the National Research Council of Italy (CNR) (link)




Fonte: ThinkGeoEnergy. "*Mapping the Icelandic Geothermal Energy Sector*", Agosto 2016. (link)

# Mundo: Potencial

| | Electrical Capacity (GW) | | | | | Shares (%) | | | CAAGR (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2030 | 2040 | 2050 | 2020 | 2030 | 2050 | 2020-2030 | 2020-2050 |
| **Total capacity** | **7 484** | **7 795** | **14 933** | **26 384** | **33 415** | **100** | **100** | **100** | **6.7** | **5.0** |
| Renewables | 2 707 | 2 994 | 10 293 | 20 732 | 26 568 | 38 | 69 | 80 | 13 | 7.5 |
| Solar PV | 603 | 737 | 4 956 | 10 980 | 14 458 | 9 | 33 | 43 | 21 | 10 |
| Wind | 623 | 737 | 3 101 | 6 525 | 8 265 | 9 | 21 | 25 | 15 | 8.4 |
| Hydro | 1 306 | 1 327 | 1 804 | 2 282 | 2 599 | 17 | 12 | 8 | 3.1 | 2.3 |
| Bioenergy | 153 | 171 | 297 | 534 | 640 | 2 | 2 | 2 | 5.7 | 4.5 |
| *of which BECCS* | - | - | *28* | *125* | *152* | - | *0* | *0* | *n.a.* | *n.a.* |
| CSP | 6 | 6 | 73 | 281 | 426 | 0 | 0 | 1 | 28 | 15 |
| Geothermal | 15 | 15 | 52 | 98 | 126 | 0 | 0 | 0 | 13 | 7.4 |
| Marine | 1 | 1 | 11 | 32 | 55 | 0 | 0 | 0 | 34 | 16 |
| Nuclear | 415 | 415 | 515 | 730 | 812 | 5 | 3 | 2 | 2.2 | 2.3 |
| Hydrogen-based | - | - | 139 | 1 455 | 1 867 | - | 1 | 6 | n.a. | n.a. |
| Fossil fuels with CCUS | 0 | 1 | 81 | 312 | 394 | 0 | 1 | 1 | 66 | 25 |
| Coal with CCUS | 0 | 1 | 53 | 182 | 222 | 0 | 0 | 1 | 59 | 22 |
| Natural gas with CCUS | - | - | 28 | 130 | 171 | - | 0 | 1 | n.a. | n.a. |
| Unabated fossil fuels | 4 351 | 4 368 | 3 320 | 1 151 | 677 | 56 | 22 | 2 | -2.7 | -6.0 |
| Coal | 2 124 | 2 117 | 1 192 | 432 | 158 | 27 | 8 | 0 | -5.6 | -8.3 |
| Natural gas | 1 788 | 1 829 | 1 950 | 679 | 495 | 23 | 13 | 1 | 0.6 | -4.3 |
| Oil | 440 | 422 | 178 | 39 | 25 | 5 | 1 | 0 | -8.3 | -9.0 |
| Battery storage | 11 | 18 | 585 | 2 005 | 3 097 | 0 | 4 | 9 | 42 | 19 |

Fonte: IEA. "Net Zero by 2050 A Roadmap for the Global Energy Sector". Maio 2021, p. 198 (link)

Renováveis com maior média de crescimento anual:

1º

2º

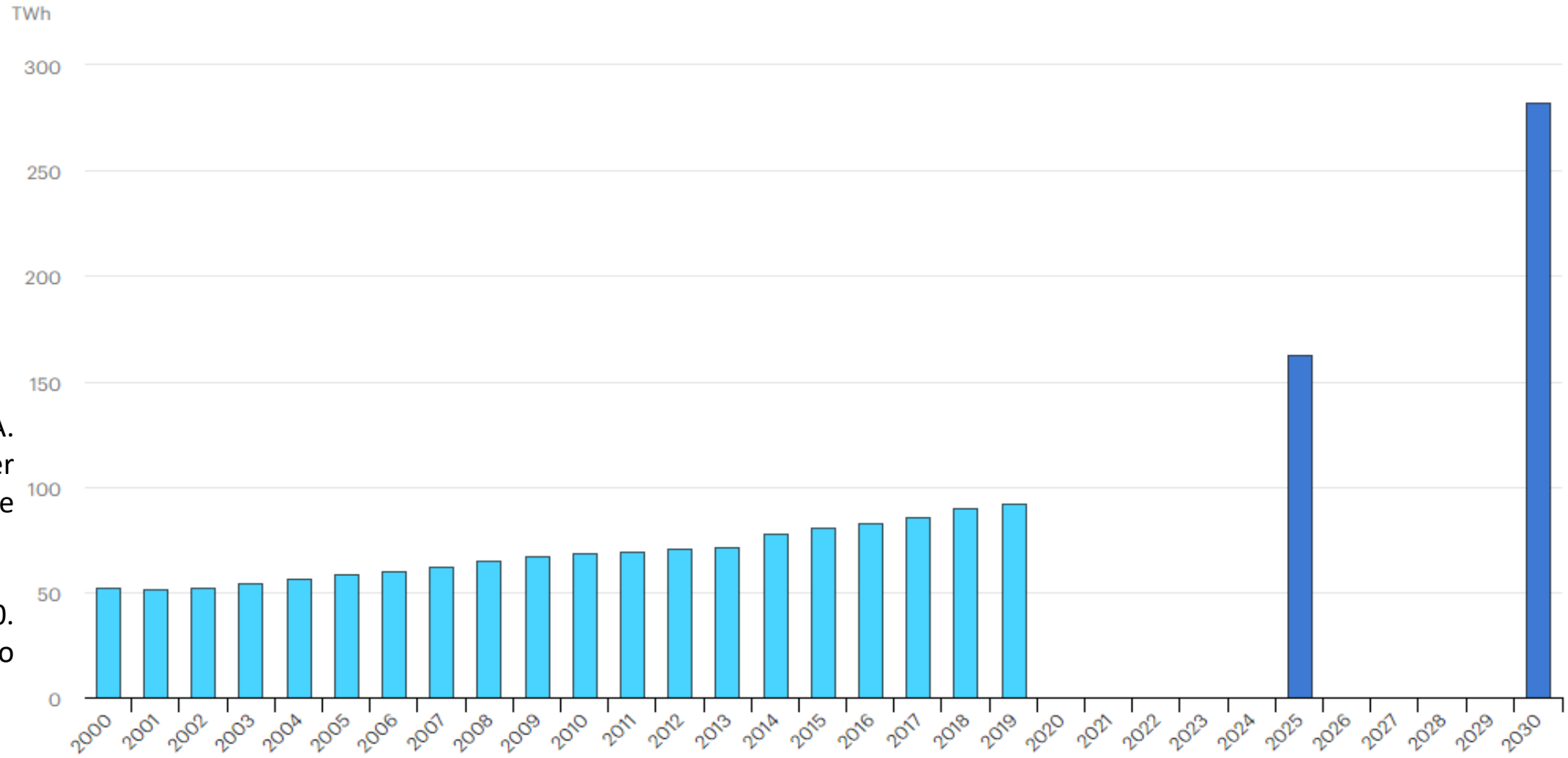
3º

4º

5º

# Mundo: Potencial

Geothermal power generation in the Sustainable Development Scenario, 2000-2030




Fonte: IEA. Geothermal power generation in the Sustainable Development Scenario, 2000-2030. Tracking Report, junho 2020. (link)

# Dados da América Latina e Caribe

# ACL

## Installed Geothermal Capacity in Latin America and the Caribbean June 2019


- MÉXICO
  - 950 MW
  - **1** Cerro Prieto - 578 MW
  - **2** Las Tres Vírgenes - 10 MW
  - **3** Domo San Pedro - 26 MW
  - **4** Los Azufres - 241 MW
  - **5** Los Humeros - 95,6 MW
- GUATEMALA
  - 49 MW
  - **6** Amatitlan - 25 MW
  - **7** Zunil - 24 MW
- EL SALVADOR
  - 204 MW
  - **8** Ahuachapan - 95 MW
  - **9** Berlin - 109 MW
- HONDURAS
  - 38 MW
  - **10** Platanares - 38 MW
- NICARAGUA
  - 150 MW
  - **11** San Jacinto- Tizate - 72 MW
  - **12** Momotombo - 78 MW
- COSTA RICA
  - 207 MW
  - **13** Las Pailas - 42 MW
  - **14** Miravalles - 165 MW
- BOLIVIA
  - 0 MW
  - **15** Poject at Laguna Colorada - 100 MW
- CHILE
  - 48 MW
  - **16** Cerro Pabellon Plant - 48 MW
- GUADELOUPE (France)
  - 16 MW
  - **17** Bouillante - 16 MW

Fonte: BID, 2020. Dados referentes a Jul/2019 (link)

# ACL

## Market Commentary from **ThinkGeoEnergy**

MEXICO
25 MW Los Azufres III-2 Phase 2 geothermal plant in construction, is expected to start in 2019. Around 25 additional projects with permits for exploration.

GUATEMALA
Up to 5 projects in early stages of development that could add 30 MW.

EL SALVADOR
6 MW extensión of Berlin geothermal plant, tender concluded, expected start of construction in 2020, one additional project at early stages of development at Chinameca.

HONDURAS
Up to 5 projects that could add more than 80 MW.

PERU
Up to 17 identified prospects, some of them with exploration permits.

BOLIVIA
5 MW pilot project tender for drilling and EPC contract awarded for Laguna Colorada project.

CHILE
30 MW Cerro Pabellon expansion project under way with expected COD second half of 2021. Several other prospects and one project were recently awarded an exploration permit.

ARGENTINA
A tender was discussed for the Copahue field, but nothing has been reported since.

NICARAGUA
Up to 3 projects in early stage of development that could add more than 150 MW.

COSTA RICA
55 MW Las Paillas II geothermal plant in construction, expected start in 2019, as reported earlier this year..

PANAMA
Potential being explored for development.

COLOMBIA
Colombia is generating significant interest and we are seeing strong public sector and multilateral support for geothermal.

ECUADOR
Four potential projects with initial early exploration work done, potential up to 50 MW.

GUADELOUPE (France)
10 MW Bouillante expansion planned with planned COD 2021.

DOMINICA
Funding announced for 7 MW geothermal power plant project, Drilling concluded and tender for power plant expected soon

ST. VINCENT & GRENADINES
Drilling start for 10 MW Project – May 2019

MONTSERRAT (UK)
Geothermal project expecting a decision. Drilling in one of three wells expected to begin as well.

ST. KITTS & NEVIS
10 MW Project on Nevis concluded tests on exploratory well drilled in 2018, funding being sought. Efforts on exploring potential development on St. Kitts continue.

"Fonte geotérmica: usinas em operação e potenc
Fonte: BID, 2020. Dados referentes a Jul/2019 (Harnessing geotherm

# América Latina e Caribe

## El Salvador


**Produzem aproximadamente 25% de toda eletricidade consumida no país**

Início da operação: 1975
Energia nacional produzida: 11%
Potência instalada: 95 MW
- Unidade 1: 30 MW (1975)
- Unidade 2: 30 MW (1976)
- Unidade 3: 35 MW (1981)

Início da operação: 1992
Energia nacional produzida: 12%
Potência instalada: 115,4 MW
- Unidade 1: 5 MW (1992)
- Unidade 2: 5 MW (1992)
- Unidade 3: 28,1 MW (1999)
- Unidade 4: 28,1 MW (1999)
- Unidade 5: 40 MW (2007)
- Unidade 6: 9,2 MW (2007)

Fonte: LAGEO (link)

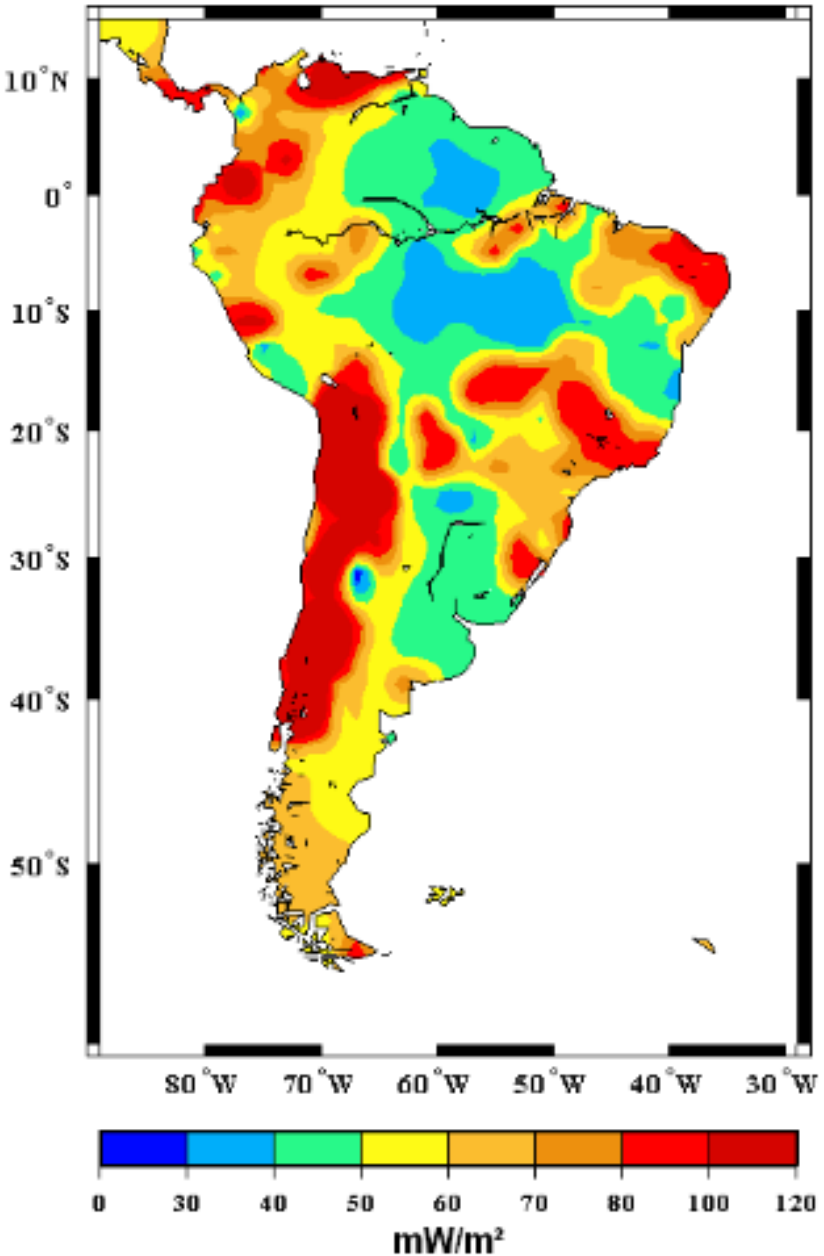
## Figure 2: Tectonic plates and global geological activity


Adapted from National Park Service (U.S.), 2014

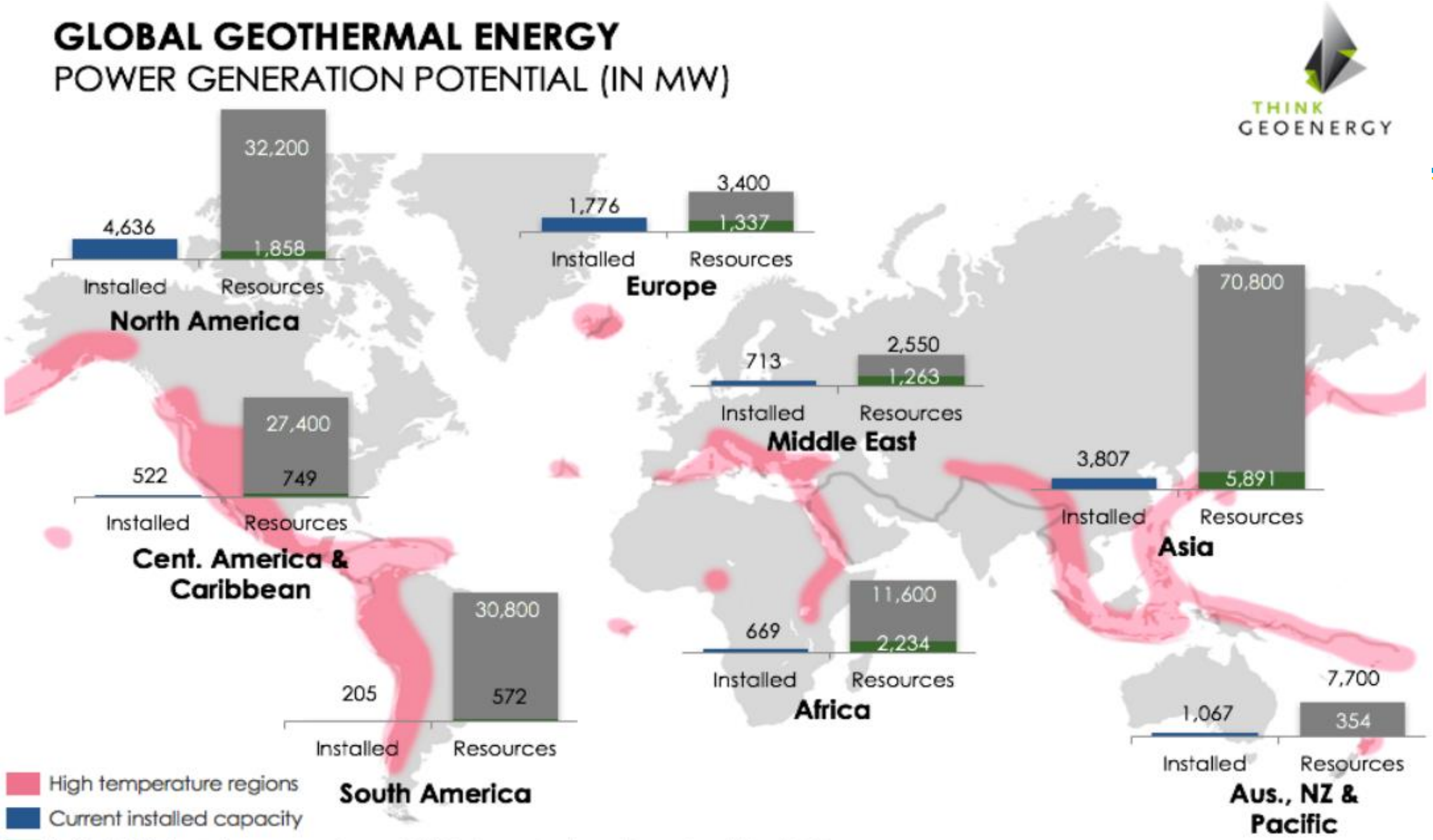
Fonte: IRENA (2017) Geothermal Power: Technology Brief (link)

# América Latina e Caribe

**Mapa de fluxo de calor geotérmico para a América do Sul**




Fonte: HAMZA, V. M; CARDOSO, R. R.; PONTE NETO, C. F. Spherical harmonic analysis of earth's conductive heat flow. International Journal of Earth Sciences, 2008. (link)




Fonte: ThinkGeoEnergy. "*Mapping the Icelandic Geothermal Energy Sector*", Agosto 2016. (link)

# Dados do Brasil

# Brasil

- Devido à característica geológica do país de baixa e média entalpia, a fonte geotérmica é **usada unicamente para fins de uso direto**, como recreação, em parques de fontes termais (ex.: Caldas Novas - GO, Piratuba - SC, Araxá - MG, Olímpia, Águas de Lindóia e Águas de São Pedro - SP).

- Apenas algumas regiões no estado de Minas Gerais e as ilhas de Fernando de Noronha e Trindade parecem ter temperaturas subsuperficiais caracterizadas como de alta temperatura.

- O aproveitamento demanda investimentos em estudos e tecnologias para a sua aplicação indireta, para a geração de energia elétrica (CAMPOS et al, 2017).

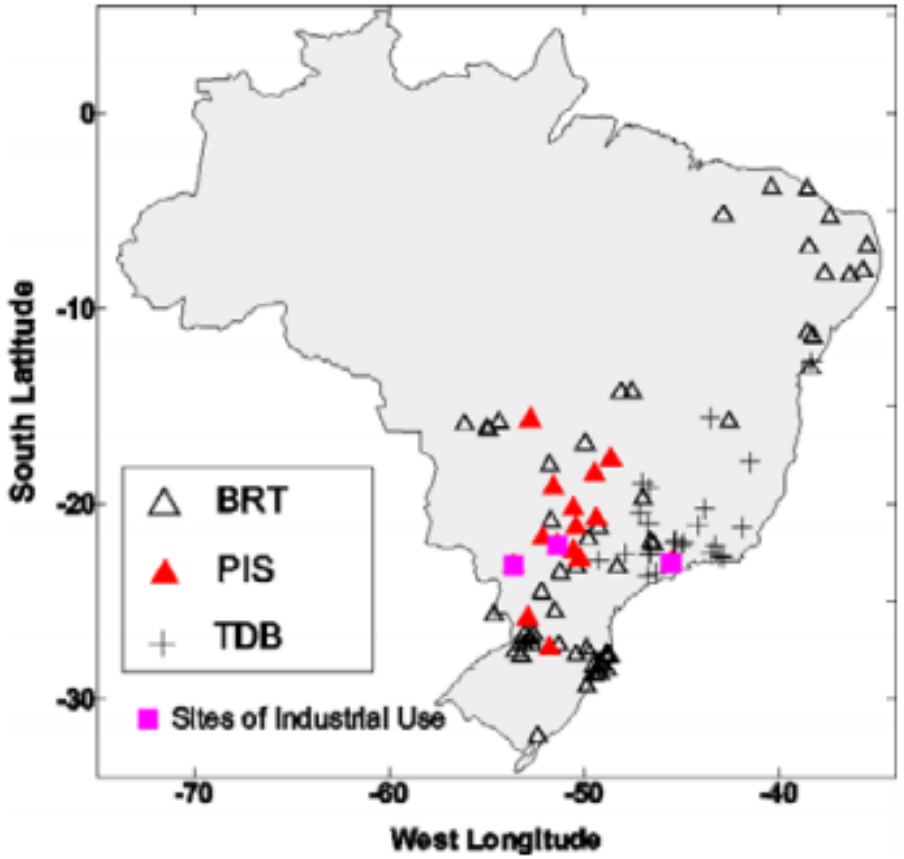
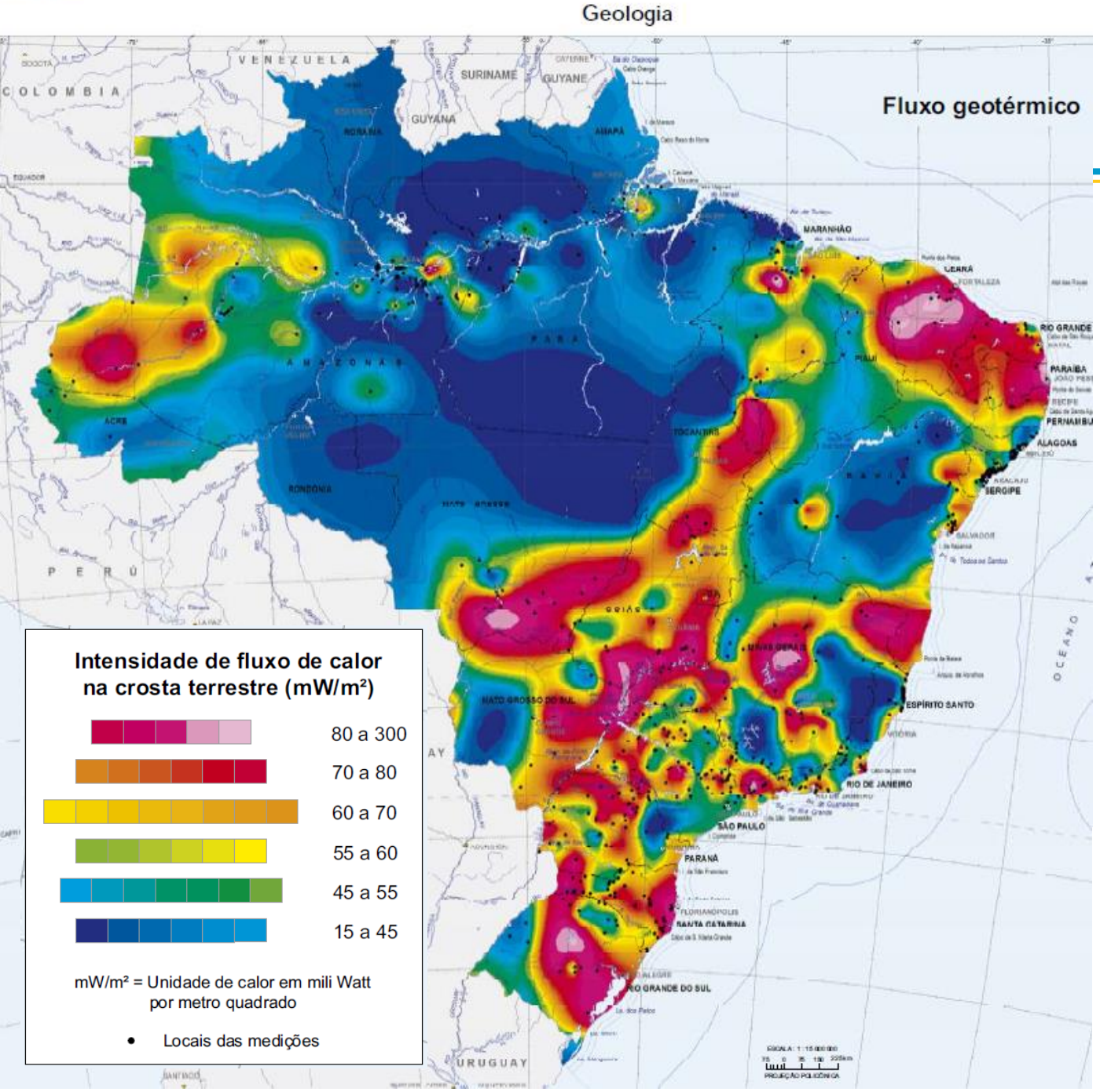



**Figure 7 Locations of major geothermal systems under development.**

BRT = Bathing, Recreation and Tourism
PIS = Potential for Industrial use and Space heating
TDB = Therapeutic, Drinking and Bathing

Fontes: HAMZA, V. M.; GOMES, A. J. L.; FERREIRA, L. E. T. Status Report on Geothermal Energy Developments in Brazil. *Proceedings World Geothermal Congress,* Turquia, abril 2005. (link)
CAMPOS et al. Um panorama sobre a energia geotérmica no Brasil e no Mundo: Aspectos ambientais e econômicos. Revista Espacios. v. 38, n. 1, 2017. (link)
VIEIRIA, F. P.; GUIMARÃES, S. N. P.; HAMZA, V. M. Updated Assessment of Geothermal Resources in Brazil. *14th International Congress of the Brazilian Geophysical Society.* Rio de Janeiro, 2015. (link)




# Mapa Geotérmico do Brasil

- 6.430.000 km² de bacias sedimentares
  - 4.880.000 km² terrestres (60% do total)
    - 1.550.000 km² na plataforma continental.

- Podem ser alvo de interesse para exploração do uso indireto pelas dimensões e especialmente pela presença de grandes províncias ígneas (inclusive do tipo geopressurizado*)

* Com água salobra quente localizada *em áreas grandes* (não em pontos quentes pequenos e localizados, próximos a superfície), *profundas* (3.000 m a 6.000 m) e normalmente *submetidas a pressões de ate 10.000 psi.* A energia potencialmente recuperável desses reservatórios é imensa, porém a tecnologia para explorá-la ainda precisa ser desenvolvida.

Fontes:
IBGE, Observatório Nacional, Coordenação de Geofísica, Laboratório de Geotermia (link)
CORRÊA, Adriana. “Energia geotermal – o que é, usos e presença no Brasil”. IGEO (link)
HINRICHS, R. A., KLEINBACH, M., REIS, L. B. Energia e Meio Ambiente. São Paulo: Cenage Learning, 2014, p. 723.

# Brasil

- Principal obstáculo: alto investimento inicial de capital necessário para perfuração e instalação de sistemas de produção e distribuição, além dos custos de operação e manutenção do campo (HAMZA et al., 2005).

- O potencial de exploração em larga escala de água geotérmica de baixa temperatura para uso industrial e aquecimento espacial é considerado significativo nas partes centrais da bacia do Paraná onde as estações frias de inverno prevalecem sob condições climáticas subtropicais. (VIEIRA et al., 2015)

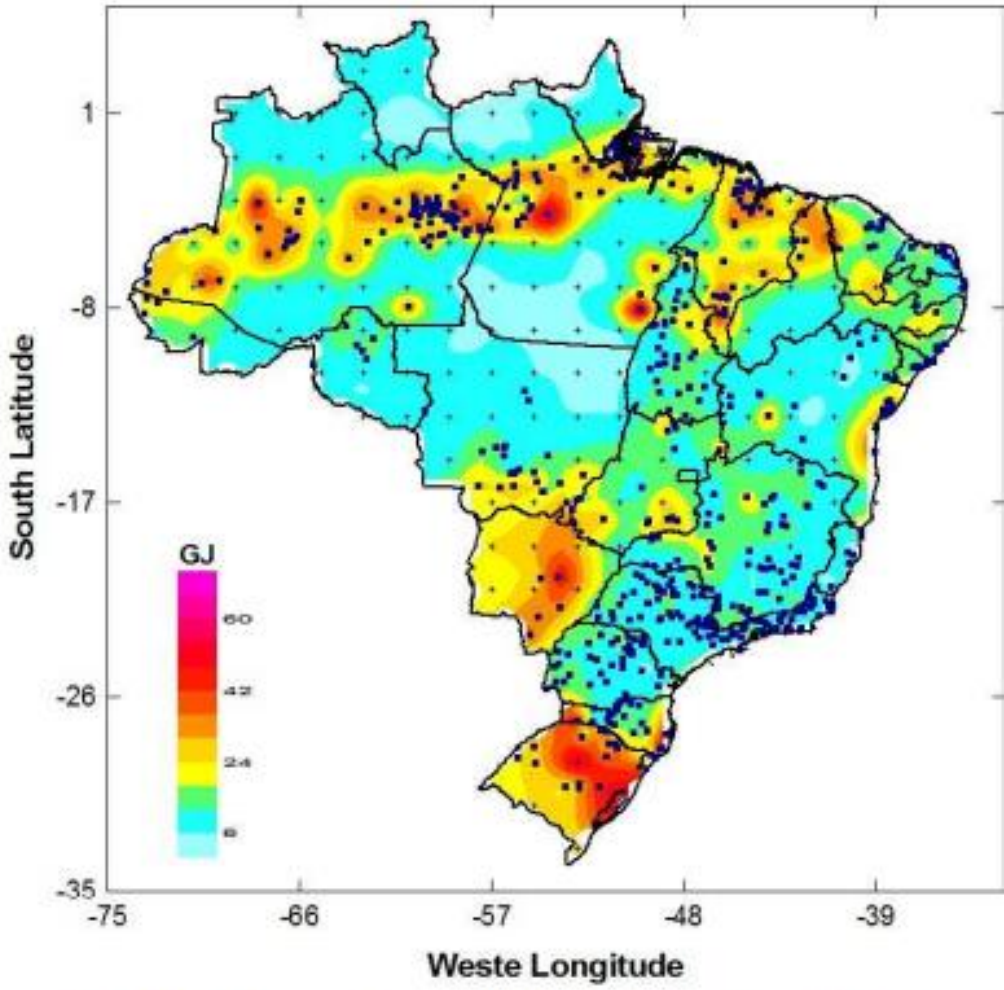



*Figure (4)*. Map of recoverable resource (in GJ) referred to depth of 3 km.

Fontes: HAMZA, V. M.; GOMES, A. J. L.; FERREIRA, L. E. T. Status Report on Geothermal Energy Developments in Brazil. *Proceedings World Geothermal Congress,* Turquia, abril 2005. (link)

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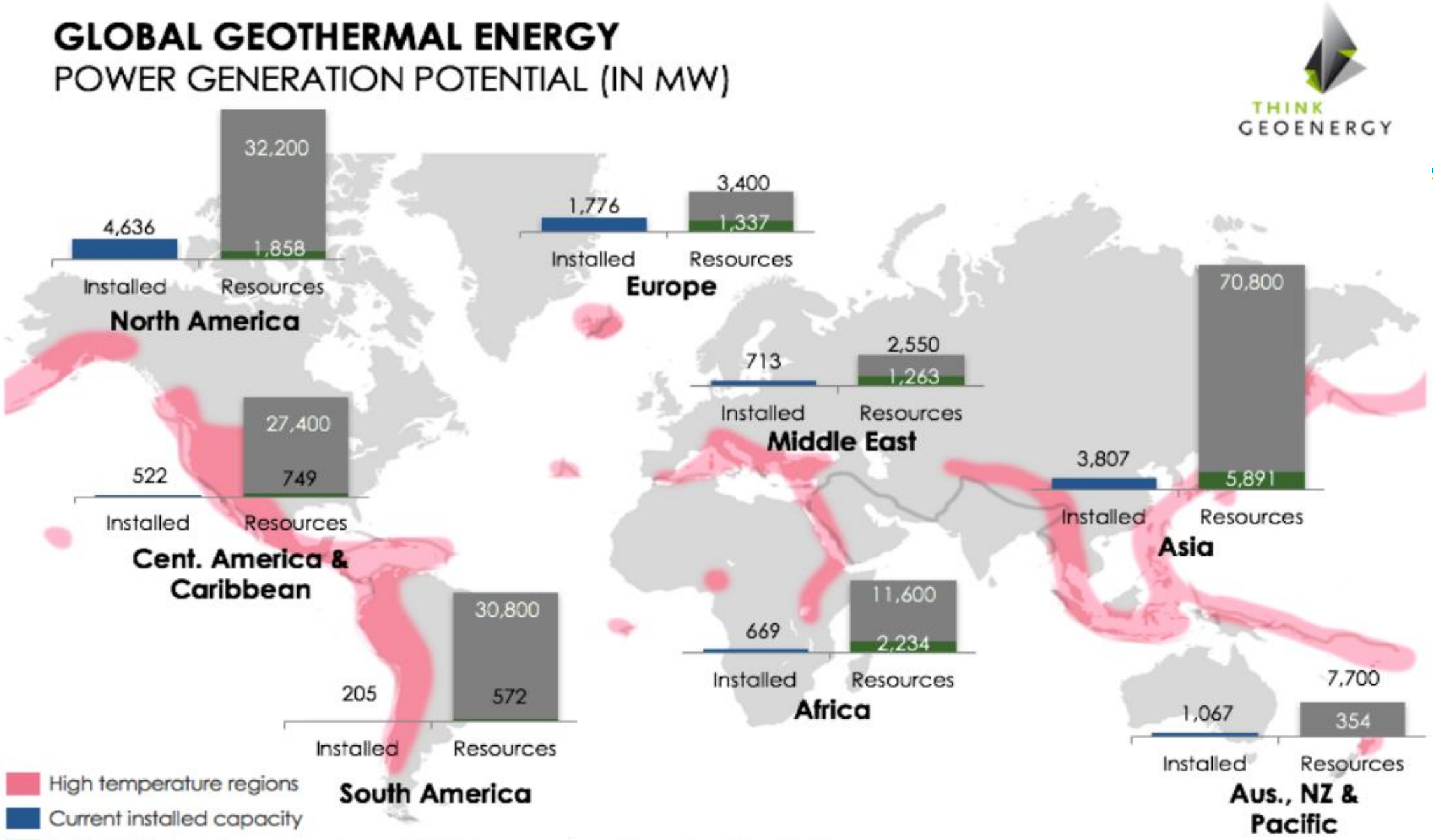


Fonte: ThinkGeoEnergy. "*Mapping the Icelandic Geothermal Energy Sector*", Agosto 2016. (link)

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# Obrigado!

## Rodrigo Mota Rodi