Updated Assessment of Geothermal Resources in Brazil - 2020

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ABSTRACT

Assessment of geothermal resources of Brazil have been carried out based on updated evaluation of recent geothermal studies. Results of data acquired at 825 sites were employed for this purpose. The total resource base, referred to accessible depth limit of 3km, is found to be 1,823 TJ. A significant number of low temperature geothermal resources have been identified in the continental area, but the potential for high temperature geothermal systems appears to be restricted to the Atlantic islands of Fernando de Noronha and Trindade. Sites with notable geothermal potential include western parts of the state of Santa Catarina, Caldas Novas (Goiás), southern parts of the State of Tocantins, southeastern region of the State of Minas Gerais and western parts of the State of Pernambuco. These sites are located along a sinuous, approximately north-south trending belt in the central parts of Brazil. The recoverable resources have been calculated based on regionally averaged values of porosity and permeability. It is estimated to be of the order of 10 TJ, but only a small fraction is being currently exploited. The total capacity of low temperature geothermal systems under economic exploitation is estimated at 365 MWt, while the annual energy use is estimated to be of the order of 6,500 TJ. About a dozen of the spring systems account for the bulk of this capacity. Most of them are located in west central Brazil (in the states of Goias and Mato Grosso) and in the south (in the state of Santa Catarina). The potential for large scale exploitation of low temperature geothermal water for industrial use and space heating is considered to be significant in the central parts of the Paraná basin.

In addition, studies have been carried out on very low geothermal energy, also designated as shallow geothermal energy (SGE),for space conditioning purposes including geothermal heat pump and geothermal air conditioning systems. A total of nine academic studies involving SGE systems has been identified. The first very low temperature geothermal system has been implemented in 1996 in the state of Rio de Janeiro, to supply the heating and cooling need of a house thanks to a geothermal heat pump system. Since then, more than 15 studies have been conducted by universities and companies, showing its technical viability, and two additional plants have been constructed. The largest one is a seawater-geothermal plant constructed in Rio de Janeiro in 2015, supplying the cooling demand of the emblematic "Museum of Tomorrow" and the other one is a geothermal heat pump system implanted in a farm house in the state of Parana. In July 2019, Brazil is totalizing a very low temperature geothermal cooling production of 2.3 MW and a very low temperature geothermal heating production of 0,05 MW. This geothermal production is expected to increase in the coming years regarding the ongoing projects identified as part of this state-of-the-art. Among these projects, four of them are planning the implantation of new SGE plants and one of them is an exhaustive study mapping the potential of the technology in Southern Brazil.

1. INTRODUCTION

The energy matrix of Brazil is composed mainly of renewable resources, with predominance of hydraulic energy, which constitute 65,2% of the internal supply. The renewable resources accounts for 80.4% of the internal demand for electrical energy, which includes both internal production as well as imports. According to recent estimates (EPE, 2018) the total energy generation in Brazil is estimated at about 302 million tons of oil equivalent (TOE). Systems based on the use of hydrocarbon resources, hydroelectric power generation and biomass systems account for nearly 90,5% of this total. According to recent compilations of information on energy use geothermal contribution is estimated to be over 360MWt. Geothermal springs are major public attractions in Brazil and have contributed to significant local and regional tourist developments in specific areas. Lack of systematic studies has contributed to poor understanding of the physical and chemical characteristics of geothermal resources and their regional distribution. Geothermal energy sources are not directly used for electrical power generation and hence not formally mentioned in energy matrix calculations by the National Council of Energy Research (CNPE). Figure 1 provides a summary of the main systems that make up the energy matrix of Brazil, modified with inclusion of geothermal contribution indicated by the red colored line, which is estimated to be about 0.03%.

Early works on evaluation of potential for geothermal energy and assessment of resources in Brazil were carried out by Hamza et al (1978) and Hamza and Eston (1983). These works made extensive use of the results of heat flow measurements. At the beginning of the last decade attempts were made for assessment of resources associated with thermal springs in the states of Mato Grosso, Goiás and Tocantins. The results of this work, carried out in collaboration with the International Institute of Geothermal Research (IIRG) of Italy, were discussed by Hamza (2003). The spatial distributions of these earlier estimates of resource base have been examined by Hamza et al (2005). A major weakness of these earlier studies is that the resource estimates were based mainly on local values of geothermal gradients and heat flow. With the exception of the studies by Hamza et al (2005) few attempts have been made in incorporating information on regional geologic and geophysical characteristics of subsurface strata in resource assessments. Hamza et al (2010) presented resource assessments for 2º x 2º equal area grid system. This approach took into consideration not only available data sets on near surface temperatures and heat flow but also supplementary information on regional lithologic and hydrologic characteristics of subsurface strata, that have direct bearings on the occurrence of geothermal resources. In the work of Vieira and Hamza (2019) the procedure adopted has been similar, but assessments were made for an accessible depth limit of 3km.

In these earlier works, no attempts were made to classify eventual differences in the thermal and physical characteristics of deep–seated resources. In the present work, the assessment scheme adopted allow for classification of resources into broad categories, namely hot wet rocks (HWR), hot dry rocks (HDR) and low enthalpy (LE).

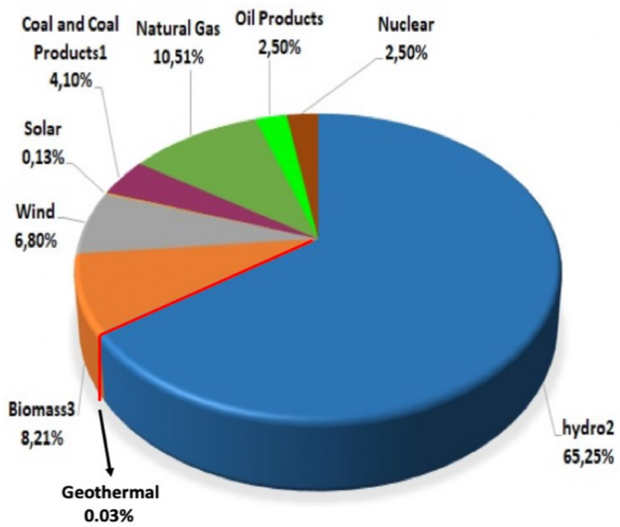

Figure 1: Updated energy matrix of Brazil. The red line indicates contribution of geothermal energy resources. (Adapted with modification, from Brazilian Energy Balance, EPE, 2018).

2. SOURCES OF GEOTHERMAL DATA

Sources of data employed in the present work include results of temperature measurements carried out in drill holes, mines and oil wells. These have been classified as per the methods employed for determinations of thermal gradients: aquifer temperature (AQT), bottom-hole temperature (BHT), stable bottom-temperature (SBT), incremental temperature logs (CVL/ITL), and geochemical (GCL). The locations of these measurements are indicated in the map of Figure 2.

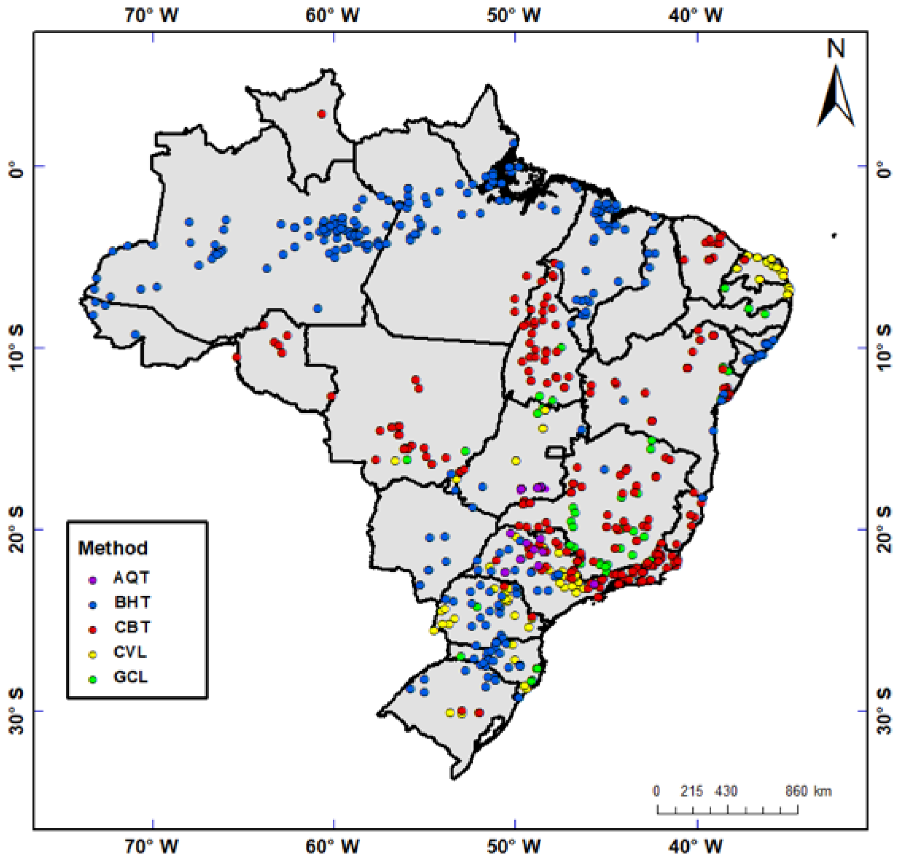

Figure 2: Locations of geothermal studies in Brazil.

In addition, basic data on physical and chemical characteristics of thermal spring systems have been compiled initially by Hurter et al (1983). The later compilations by the Geothermal Laboratory of the National Observatory (Brazil) also included data on thermo-physical properties of the main geologic formations in the upper crust as well as estimates of terrestrial heat flow (Vieira and Hamza, 2014). The details of thermal spring systems with data on temperatures and flow rates are provided in table (3) of the Appendix. Thermal springs are relatively more abundant in the southern state of Santa Catarina and central states of Mato Grosso and Goiás. Most of the springs have temperatures lower than 70ºC. Wells intercepting deep aquifers are also used for extraction of thermal waters in several localities in the Parana basin.

3. CRUSTAL TEMPERATURES

Obviously, such classification schemes depend on determinations of accurate vertical distributions of temperatures in the upper crust. A simple one-dimensional heat conduction model, that incorporates the effects of vertical variations in thermal conductivity and radiogenic heat production, was used for this purpose. The relation for "excess temperature" (ΔT) over the mean surface temperature is given by the relation:

$$\Delta T = \frac{q_0}{\lambda}\, d - \frac{A_0 D^2}{2\,\lambda}\left(1 - e^{-z/D}\right) \qquad (1)$$

where q_0 is the surface heat flux, A_0 radiogenic heat productivity and k the thermal conductivity. The values of A_0 is derived from empirical relations relating crustal seismic velocities with radiogenic heat productivity. The thermal conductivity values of the sedimentary layers were derived from the heat flow database (Vieira and Hamza, 2019). Regional distributions of excess temperatures were calculated based on equation (1) for depth levels of 3, 4, 5 and 6 km. The results obtained are illustrated as vertical stacked maps in Figure 3.

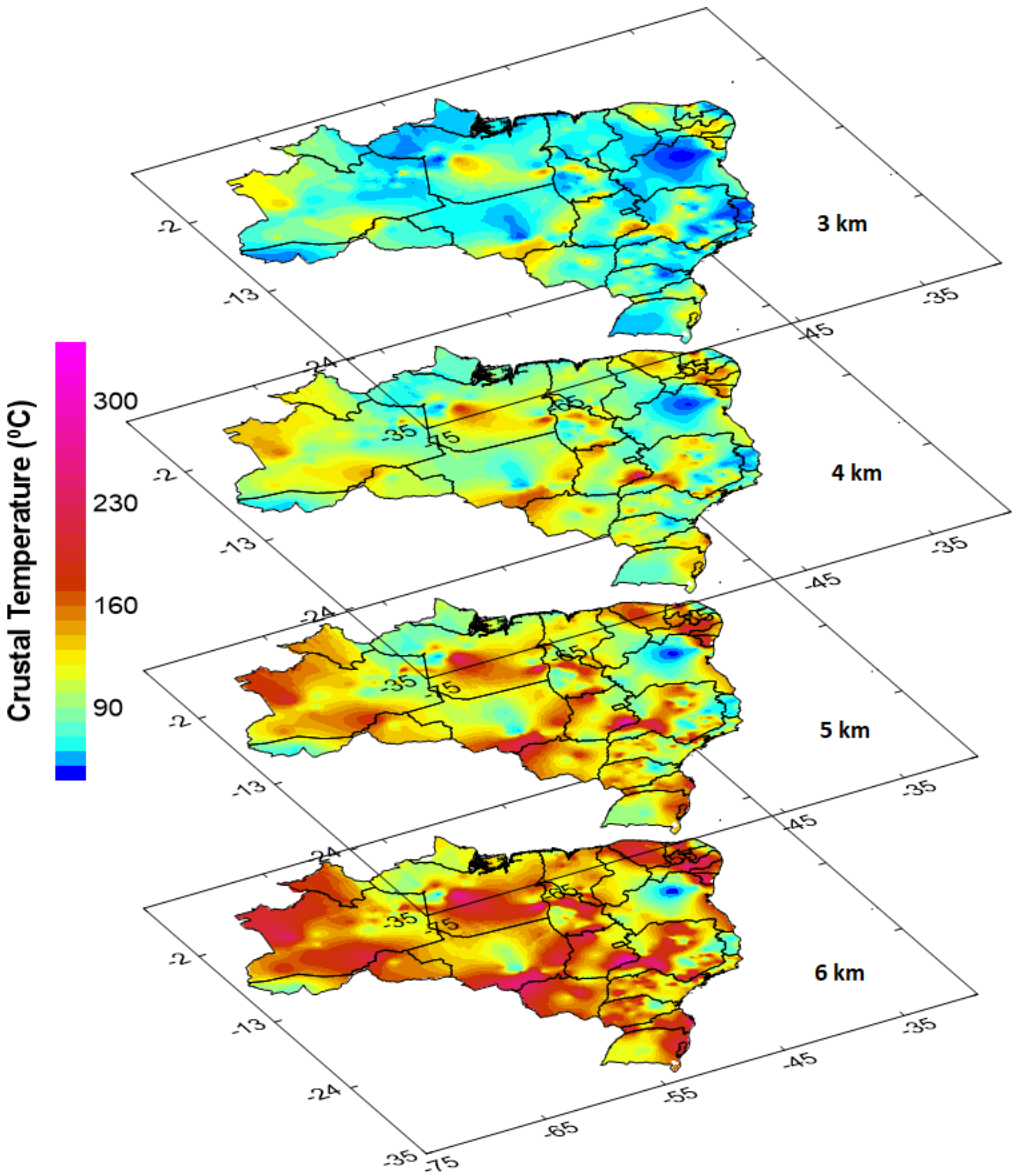

Figure 3: Crustal temperature maps, stacked from top to bottom, for depths respectively of 3, 4, 5 and 6 km (Vieira and Hamza, 2019).

Note that the maps of Figure (3) indicate excess temperatures in the range of 80 to 140°C, at depths greater than 3km, in many parts of the Parana basin, that spans over parts of the States of Rio Grande do Sul, Santa Catarina, São Paulo and Mato Grosso. Similar trends are also projected for the central parts of the Amazonas and Parnaiba basins. Also, pockets of temperatures with values higher than 140°C may occur at depths greater than 4km in the southern parts of the states of Goiás and in the northeastern region of the structural province of Borborema. Temperatures higher than 150°C are expected at depths greater than 5km in the southern parts of the state of Mato Grosso, isolated pockets in the Parana basin and also in the Atlantic island of Fernando de Noronha.

4. CALCULATIONS OF RESOURCE BASE

The resource base calculations were carried out following the methodology proposed in earlier studies (e.g. Muffler and Cataldi, 1978). Volumetric method was considered adequate for the present purpose. In this method the resource base is calculated as the excess thermal energy in the layer, the reference value being the surface temperature. The resource base (Q_{RB}) of thickness d, associated with the temperature distribution given by equation (1), is calculated using the relation:

$$Q_{RBi} = \rho_i \, C_{pi} \, A_i \, d_i \, (T_i - T_0) \qquad (2)$$

where ρ_i is the average density of the i^{th} layer, c_{pi} the specific heat, Ai the area of the cell, T_i the bottom temperature and T_0 upper surface temperature. In the present work a reference depth of 3km was chosen in calculations of the resource base. The regional distribution of resource base, referred to this depth limit is illustrated in the map of Figure 4.

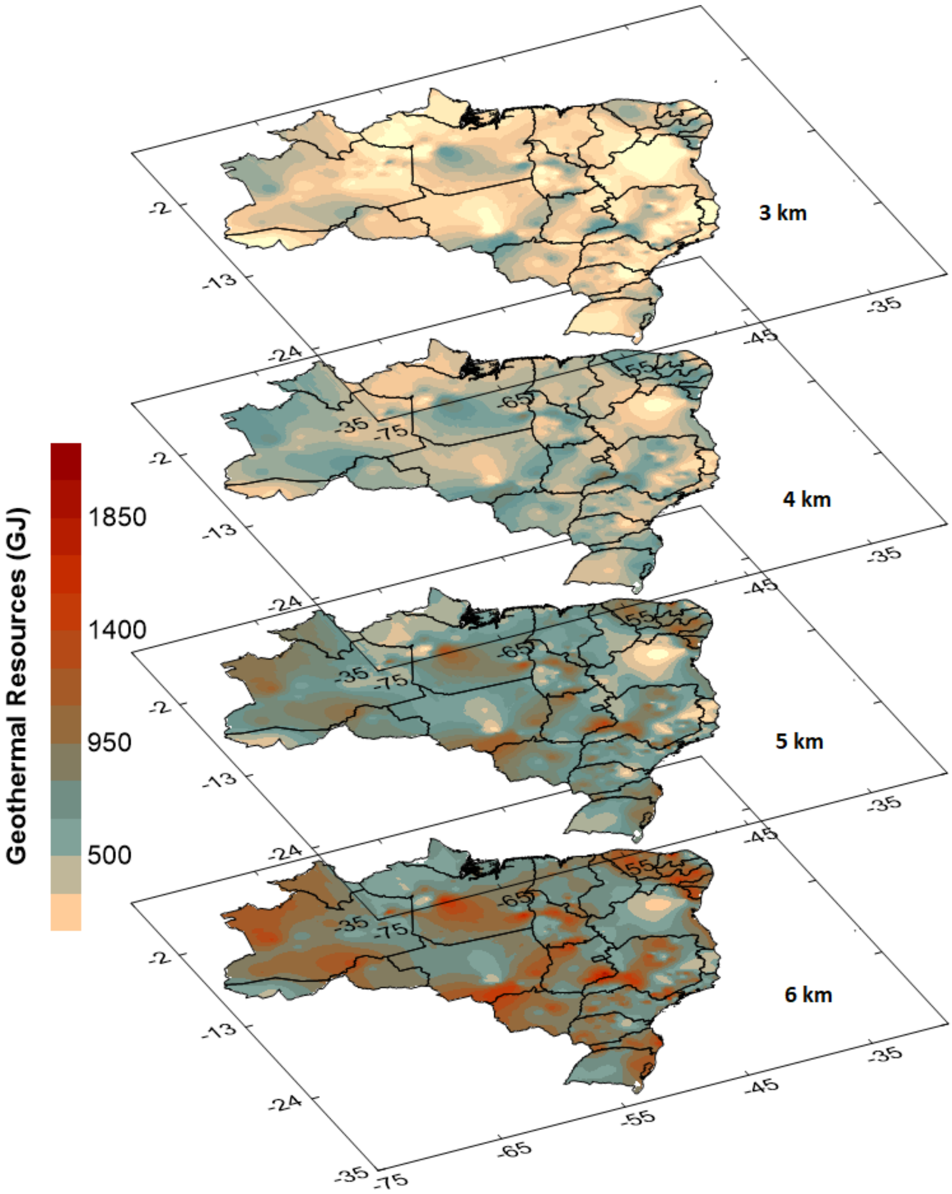

Figure 4: Vertical stacking of maps providing 3D perspective of resource base per unit area (RBUA), at depth levels of 3, 4, 5 and 6 km (Vieira and Hamza, 2019).

5. REGIONAL SETTINGS OF RESOURCES

Though maps of Figure 4 provide an overall picture of the distribution of resources these are of limited use in providing quantitative information regarding geothermal systems associated with regional blocks. Hence calculations were made for conveniently chosen systems of blocks. In many cases, the boundaries of such regional blocks coincide roughly with those proposed in geologic studies. Such advances have allowed resource assessments for 1377 localities in the continental area of Brazil.

The results obtained on the basis of data sets compiled in the present work and using equation (2) are given in Table (A) for the 24 provinces of Brazil where the maximum depth considered is 6 km. The letter N in the second column of this table refer to the number of estimates, while the third column refer to areas of each province. The fourth and fifth columns give the estimates for the resource base (RB) and recoverable resource (RR) for each province, expressed in unit of 10^{21} joules. However, it is clear that resource base per unit area (RBUA) is a better indicator of the geographic distribution. Given in the last columns of this table are values of RBUA and RRUA expressed in units of gigajoules per square meter (GJ/m^2).

Note that relatively large values of RBUA occur in provinces affected by magmatic and/or tectonic episodes. Examples are Atlantic island of Fernando de Noronha, the alkaline intrusive complex of Poços de Caldas in the southwestern parts of Minas Gerais and the sedimentary basins of Pelotas and Pantanal in southern Brazil. Similar values were found for basins along the Atlantic coastal region, the examples being basins of Sergipe, Recôncavo, Potiguar, Mucuri and Campos. On the other hand, relatively low values of RBUA are found for Precambrian provinces such as Borborema, Central Precambrian Shield and Sao Francisco Craton.

Table (A) Estimates of geothermal resource base (RB) and resource base per unit area (RBUA) for the 24 geologic provinces in Brazil and depth of investigation of 6 km (* Indicates mean value).

Geologic Province	N	Area (km^2)	RB (10^{21}J)	RR (10^{21}J)	RBUA (10^9J)	RRUA (10^9J)
Fernando de Noronha	01	26	0.021	0.001	793	40
Poços de Caldas	01	544	0.56	0.028	1036	52
Pelotas	07	250000	293	14.7	1172	59
Pantanal	05	10000	3.9	0.19	1175	59
Sergipe/Alagoas	22	130000	12.5	0.63	942	47
Jatobá/Tucano/Reconcavo	32	45000	39.8	2	839	42
Barreirinhas/Ceará/Potiguar	17	35000	27.5	1.38	781	39
Mucuri/Jequitinhonha	06	10000	7.0	0.35	777	39
Campos/Espírito Santo	09	128000	96.9	4.9	757	38
Taubaté	09	4250	2.9	0.14	734	37
Paraná	191	1050000	904	45.4	872	44
Solimões	38	500000	412	20.7	823	41
Amazonas	108	515000	389	19.5	749	38
Marajó/Foz Amazonas	29	51000	39.2	1.97	771	39
Parnaíba	133	600000	430	21.6	718	36
Acre/Madre Dios	09	905000	604	30.3	667	34
Parecis	14	355000	224	11.2	635	32
B. São Francisco	120	354800	226	11.4	629	32
Tocantins	196	978000	753	37.6	805	40
Borborema	99	330000	238	11.9	727	36
Mantiqueira	119	700000	504	25.2	727	36
Central Shield	34	761868	490	24.5	643	32
Northern Shield	15	567965	325	16.2	573	29
Craton São Francisco	163	267200	157	7.8	601	30
Total/Mean	**1377**	**8548653**	**6179**	**310**	**789***	**40***

6. TYPES OF GEOTHERMAL RESOURCES

The progress obtained in assessment of resources have also allowed determinations of temperatures associated with resource systems at relatively shallow depths. For convenience we considered two categories, designated as low enthalpy (LE) and transitional from low to medium enthalpy (TLME). The low enthalpy (LE) group is characterized by temperatures in the interval 30 to 60ºC while the transitional (TLME) group is characterized by temperatures in the range of 60 to 90ºC. The geographic distributions of excess temperatures of these categories are illustrated in the two panels of Figure (5). The respective estimates of resource base (RB) and resource base unit area (RBUA) of these two categories are provided in Table (B). Note that the values of resource base (RB) are provided in unit of 10^{21} Joules while that of the RBUA are provided in unit of GJ per meter square.

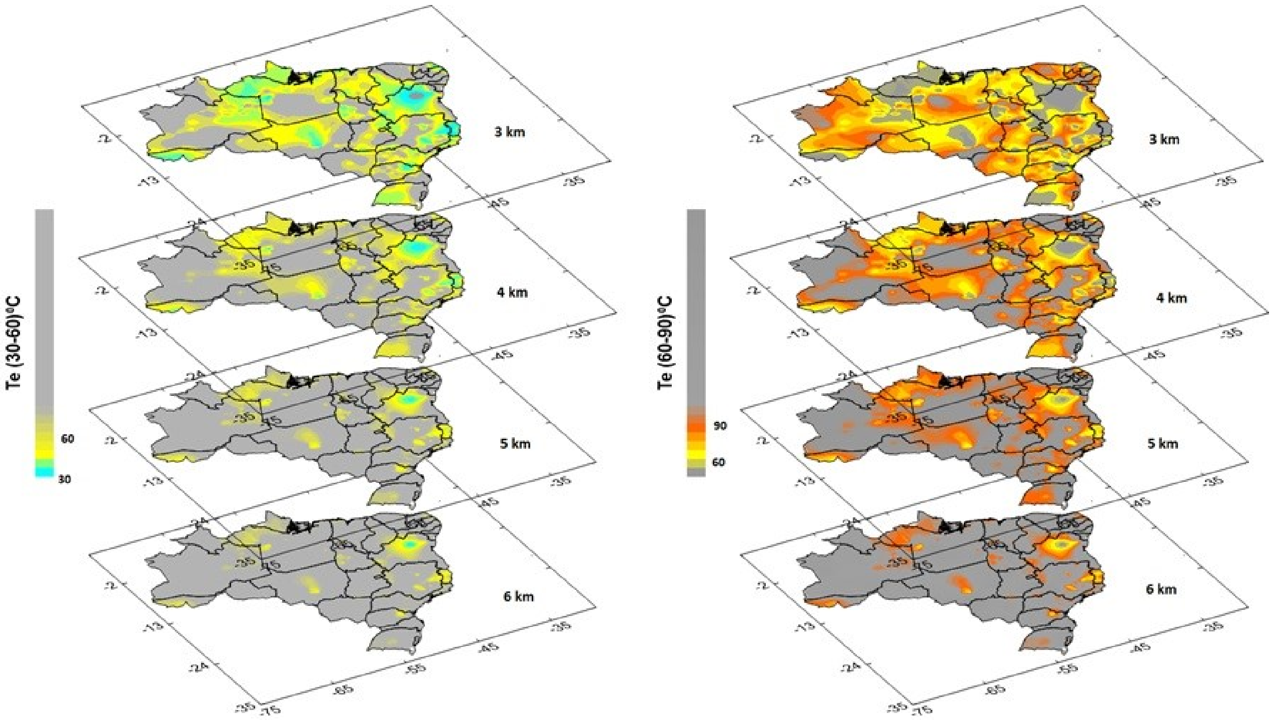

Figure 5: The geographic distributions of LE (left panel) resources with temperatures in the range of 30 to 60C and TLME (right panel) resources with temperatures in the range of 60 to 90C (Vieira and Hamza, 2019).

Table (B) Low enthalpy (LE) geothermal systems with temperatures in the range of 30 to 60°C, indicated for bathing and tourism in Brazil and temperatures in the range of 60 to 90°C, indicated for agro-industrial (* Indicates average value).

Geologic Province	Te (30 to 60°C)			Te (60 to 90°C)		
	N	RB (10^{21}J)	RBUA (10^{9}J)	N	RB (10^{21}J)	RBUA (10^{9}J)
Fernando de Noronha	03	0.00082	115	01	0.00044	186
Poços de Caldas	01	0.0083	167	06	0.0711	239
Pelotas	01	5.68	159	01	8.88	249
Pantanal	01	0.0926	167	01	11.3	204
Sergipe/Alagoas	02	0.12	136	18	2.15	232
Jatobá/Tucano/Reconcavo	15	1.52	105	09	1.81	213
Barreirinhas/Ceará/Potiguar	17	0.0895	123	14	0.168	224
Mucuri/Jequitinhonha	05	1.38	165	02	0.262	236
Campos/Espírito Santo	04	8.13	143	05	16.6	233
Taubaté	22	0.324	131	10	0.200	211
Paraná	77	65.6	163	94	97.9	225
Solimões	14	28.7	156	19	55.5	222
Amazonas	48	31.1	152	63	58.4	212
Marajó/Foz Amazonas	10	2.73	155	19	5.95	200
Parnaíba	84	55.3	148	35	33.8	214
Acre/Madre Dios	04	65.8	145	04	88.2	195
Parecis	11	37.6	140	04	19.6	224
B. São Francisco	114	48.3	150	06	3.89	219
Tocantins	153	107	157	38	30.4	212
Borborema	77	25.3	121	15	8.49	217
Mantiqueira	91	75.9	152	26	28.5	225
Central Shield	30	110	164	01	5.58	249
Northern Shield	15	74.4	141	01	8.75	231
Craton São Francisco	163	37.2	150	07	1.26	225
Total/Mean	**962**	**782.28**	**146***	**399**	**487.66**	**220***

It is possible to extend this classification scheme for higher temperatures. In the present work, we have classified resources with temperatures in the range of 90 to 150°C as those associated with hot wet rock (HWR) systems. Similarly, those with temperatures higher than 150°C are considered as those associated with hot dry rock (HDR) systems. There are indications that HWR systems with temperatures in the range of 90 to 150°C may be present at depths of 3 to 6km in intra-cratonic basins of Parana and Parnaiba. Similarly, HDR systems with temperatures higher than 150°C may be present at depths of 4 to 6 km in tectonic units such as Borborema and Tocantins.

7. UTILIZATION OF GEOTHERMAL RESOURCES

A summary of data concerning utilization of geothermal energy for direct heat for systems with inlet temperatures greater than 35°C is provided in Table 3 of the Appendix. The main applications are for process heat (P), balneology (B) and fish farming (F).

In addition, studies have also been carried out on very low temperature geothermal energy, designated as shallow geothermal energy (SGE) systems, for space conditioning purposes. This technology includes geothermal heat pump and geothermal air conditioning systems using a shallow geothermal resource with temperatures less than 30°C. A total of nine academic studies involving SGE systems has been identified. The first very low temperature geothermal system has been commissioned in 1996 in in the state of Rio de Janeiro, to supply the heating and cooling needs of a house, thanks to a geothermal heat pump system. Since then, more than 15 studies have been conducted by universities and companies, demonstrating its technical viability, and two additional plants have been constructed. The largest one is a seawater geothermal plant constructed in Rio de Janeiro in 2015, supplying the demand for cooling loads of the emblematic "Museum of Tomorrow" and the other one is a geothermal heat pump system implanted in a farmhouse in the state of Parana. In July 2019, Brazil is totalizing a very low temperature geothermal cooling production of 2.3 MW and a very low-temperature geothermal heating production of 0.05 MW. This geothermal production is expected to increase in the coming years regarding the ongoing projects identified as part of this state-of-the-art assessment. Among these projects, four of them are planning the implantation of new SGE plants and one of them is an exhaustive study mapping the potential of the technology in Southern Brazil, including a strategy proposition for advances in the technology deployment.

8. CONCLUSIONS

Assessment of geothermal resources of Brazil have been carried out based on updated evaluation of recent geothermal studies. In terms of low temperature geothermal energy, results of data acquired at 825 sites were employed for this purpose. The total resource base, referred to accessible depth limit of 3km, is found to be 1,823 TJ. A significant number of low temperature geothermal resources have been identified in the continental area, but the potential for high temperature geothermal systems appears to be restricted to the Atlantic islands of Fernando de Noronha and Trindade. Sites with notable geothermal potential include western parts of the state of Santa Catarina, Caldas Novas (Goiás), southern parts of Tocantins, southeastern region of Minas Gerais and western parts of Pernambuco. These sites are located along a sinuous, approximately north-south trending belt in the central parts of Brazil. The recoverable resources have been calculated based on regionally averaged values of porosity and permeability. It is estimated to be of the order of 10 TJ, but only a small fraction is being currently exploited. The total capacity of low temperature geothermal systems under economic exploitation is estimated at 365 MWt, while the annual energy use is estimated to be of the order of 6,500 TJ. About a dozen of the spring systems account for the bulk of this capacity. Most of them are located in west central Brazil (in the states of Goiás and Mato Grosso) and in the south (in the state of Santa Catarina). The potential for large scale exploitation of low temperature geothermal water for industrial use and space heating is considered to be significant in the central parts of the Paraná basin. In terms of very low temperature geothermal energy, there was in July 2019 three operating plants located in the states of Rio de Janeiro and Parana, totalizing an installed capacity of 2.3 MWt for space cooling and 0.05 MWt for space heating. The ongoing projects identified as part of this assessment indicate that the technology interest has been growing and various new plants built in the coming years. Additional information about the overall energy production and use are summarized in tables 1 to 8 of the Appendix.

REFERENCES

EPE, (2018) Brazilian Energy Balance for 2017 (in Portuguese), Report produced by Empresa de Pesquisa Energetica – EPE, Ministry of Mines and Energy (Brazil)

Hamza, V.M., Eston, S.M., Araújo, R.L.C. (1978) Geothermal energy prospects in Brazil: A preliminary analysis. Pure Appl. Geophysics, **117**, 180-195.

Hamza, V.M., Eston, S.M., (1983) Assessment of geothermal resources of Brazil – 1981. Zentralblatt fur Geologie und Paläontologie, 1, 128–155.

Hamza, V.M., (2003), An Appraisal of Geothermal Energy Use in Brazil, Geothermal Resources Council Transactions, v.27, 59 – 63.

Hamza, V.M., Gomes, A.J.L., Ferreira, L.E.T., (2005) Status Report on Geothermal Energy Developments in Brazil. Proceedings World Geothermal Congress, Antalya, Turkey, 24-29 April.

Hamza, V.M., Cardoso, R.R., Gomes, A.J.L., Alexandrino, C.H. (2010) Brazil: Country Update. Proceedings of the World Geothermal Congress, Bali, Indonesia, 25-29 April.

Hurter, S.J., Eston, S.M., Hamza, V.M. (1983). Brazilian Geothermal data collection, series 2: Thermal springs. Publication n^0 1233. Inst. de Pesquisas Tecnológicas do Estado de São Paulo, São Paulo, Brazil, 111p.

Muffler, L.J.P., Cataldi, R. (1978) Methods for regional assessment of geothermal resources. Geothermics, 7, 53-89.

Vieira, F.P.; Hamza, V.M. (2014) Advances in Assessment of Geothermal Resources of South America. Natural Resources, **05**, 897-913.

Vieira, F.P., Hamza, V.M. (2019) New Look at Assessment of Geothermal Resources of South America. International Journal of Terrestrial Heat Flow and Applied Geothermics. **2**; P. 46-57.

Appendix

STANDARD TABLES - NOTE: TABLES 2/8 AND 4/8 ARE NOT INCLUDED

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity)

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (Biomass, wind)		Total	
	Capacity MWe	Gross Prod GWh/yr	Capacity MWe	Gross Prod GWh/yr	Capacity MWe	Gross Prod GWh/yr	Capacity MWe	Gross Prod GWh/yr	Capacity MWe	Gross Prod GWh/yr	Capacity MWe	Gross Prod GWh/yr
In operation in December 2019			32778	111497	84294	4447599	2007	13800	1894	6443	120973	4579339
Under construction in December 2019			11,8		18863		(100)		(100)			
Funds committed, but not yet under construction in December 2019												
Estimated total projected use by 2020			32790	111497	103157	4447599	2107	13800	1994	6443		

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT FOR SYSTEMS WITH INLET TEMPERATURES HIGHER THAN 37oC. (B – BALNEOLOGY; F - FISH FARMING; P – PROCESS-HEAT)

Locality	Type	Flow Rate	Tin	Tout	Capacity (MWt)	Flow (kg/s)	Use (TJ/yr)	Capacity Factor
Presidente Epitácio	B	14	78	30.0	2.8	8	51	0.58
Preisdente Prudente	B/P	28	63	30.0	3.8	16	71	0.58
Jales	B	14	61	30.0	1.8	8	33	0.58
Fernandópolis	B	14	59	30.0	1.7	8	31	0.58
Caldas Novas	B/F	333	57	32.0	35	194	641	0.58
Mossoró	B	14	54	32.0	1.3	8	24	0.58
Arraçatuba	B	417	48	30.0	31	243	577	0.58
Caldas de Jorro	B	31	48	30.0	2.3	18	43	0.58
Taubaté	B/P	14	48	30.0	1.0	8	19	0.58
Paraguaçu Paulista	B	14	48	30.0	1.0	8	19	0.58
Cornélio Procópio	P	14	48	20.0	1.6	8	30	0.58
Foz do Iguaçu	B	14	48	20.0	1.6	8	30	0.58
Londrina	B	6	48	20.0	0.7	3	12	0.58
General Carneiro	B	152	46	30.0	10.2	89	187	0.58
Caldas	B	6	46	30.0	0.4	3	7	0.58
Três Lagoas	B	14	46	30.0	0.9	8	17	0.58
São José do Rio Preto	B	28	45	30.0	1.7	16	32	0.58
Bom Jardim	B	6	44	30.0	0.3	3	6	0.58
Juscimeira	B	8	44	30.0	0.5	5	8	0.58
Poços de Caldas	B	6	44	30.0	0.3	3	6	0.58
S.A. Leverger	B	3	42	30.0	0.1	2	3	0.58
São Vicente	B	3	42	30.0	0.1	2	3	0.58
Jaciara	B	6	42	30.0	0.3	3	5	0.58
Rio Quente	B	1667	42	32.0	70	972	1283	0.58
Lins	B	6	42	30.0	0.3	3	5	0.58

Correia Pinto	B	3	42	30.0	0.1	2	3	0.58
Barra do Garças	B	6	41	30.0	0.3	3	5	0.58
Palmeiras	B	3	40	30.0	0.1	2	2	0.58
Poxoreu	B	6	40	30.0	0.2	3	4	0.58
Rio Pardo de Minas	B	28	40	30.0	1.2	16	21	0.58
Águas Mornas	B	14	40	30.0	0.6	8	11	0.58
Palhoça	B	3	40	30.0	0.1	2	2	0.58
Piratuba	B	194	39	30.0	7.3	113	135	0.58
Rio Pelotas	B	7	39	20.0	0.5	4	10	0.58
Salgadinho	B	6	38	26.0	0.3	3	5	0.58
Alto Paraiso de Goiás	B	14	38	30.0	0.5	8	9	0.58
Gravatal	B	33	38	30.0	1.1	19	21	0.58
Marcelino Ramos	B	3	38	30.0	0.1	2	2	0.58
Nova Veneza	B	3	38	30.0	0.1	2	2	0.58
Águas Maravilhosas	B	3	38	30.0	0.1	2	2	0.58
Águas de Chapecó	B	3	37	30.0	0.1	2	1	0.58
Palmitos / Araxá	B	14	37	30.0	0.4	8	7	0.58

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2019

Use	Installed Capacity[1]	Annual Energy Use[2]	Capacity Factor[3]
	(MWt)	(TJ/yr = 10^{12} J/yr)	
Air conditioning (Cooling)	2.3		
Fish Farming			
Animal Farming			
Agricultural Drying			
Industrial Process Heat	4.2	77	0.58
Bathing and Swimming	355.9	6545.4	0.58
Other Uses			
Subtotal	362.4	6622.4	
Geothermal Heat Pumps	0.05		
Total	362.45	6622.4	0.58

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 31, 2019 (excluding heat pump wells)

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)		10			5
Production	>150° C					
	150-100° C					
	<100° C		10			5
Injection	(all)					
Total			10			10

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	2		2			2
2016	2		2			2
2017	2		2			2
2018	2		2			2
2019	2		2			2
Total	10		10			10

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	**0,3**	**0,8**	**0,5**		**80**	**20**
2000-2004	**0,1**	**0,1**	**0,5**		**80**	**20**
2005-2009	**0,1**	**0,1**	**0,1**		**80**	**20**
2010-2014	**0,1**	**0,1**	**0,1**		**80**	**20**
2015-2019	**0,1**	**0,1**	**0,1**		**80**	**20**