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Geothermal Energy Resources of India: Country Update

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ABSTRACT

India's power generation during the last four years has increased from 228,719 MWe (2014) to 356,818 MWe (2018) with coal being the primary energy source. Although the solar photovoltaic (pv) source generated electricity has increased from 24,503 MWe (2015) to 728,359 (2018), this is not reflected in the CO_2 emissions of the country. The CO_2 emissions by India has crossed 2076 million tonnes at present, up from 620 million tonnes in 2015. However, ground source heat pumps (GHPs) for space cooling have picked up pace over the past few years. Large commercial storage houses (pharmaceutical warehouses) are implementing GHP systems to save electricity bills. M/s GeoSyndicate has recently completed installing one such system for a pharmaceutical warehouse in Mumbai and several such systems are in the process of installation in Maharashtra. The $\delta^{11}B$ values (2.5 to 27 per mil) suggests involvement of ancient marine sediments during the circulation of thermal waters. The study indicates high reservoir temperatures (~ 250 °C) towards the southern part of the west coast geothermal province. The geochemistry of Tulsishyam thermal springs in Gujarat indicate circulation of the thermal waters within the high radiogenic granites. The uranium, thorium and potassium contents of the granites are the main source of heat and the surface heat flow values estimated vary from 53-90 mW/m^2 (Singh et al., 2018). Based on the carbon isotope signature, the estimated CO_2 emissions from the Himalayan thermal springs is about 29 million mol/year (Tiwari et al., 2016). Investigation on the thermo-mechanical properties of high heat generating granites (potential candidate for EGS site) from Bundelkhand, Madhya Pradesh has been carried out.

1. INTRODUCTION

World energy demand increased by 2.1 % relative to 0.9 % in the previous year. India and China shared major part of this increase amount to 40%. This rise is supported by fossil fuels. With increase in energy demand, the CO_2 emissions in 2018 globally showed an increase of 1.7 % amounting to about 33 Gt CO_2 (Boden et al., 2011). Major emissions are recorded from the power sector, especially from coal based thermal power plants. Coal based power plants contributed about 10Gt of CO_2 to the total emissions mainly from India and China and USA (Boden et al., 2011). Although India is generating considerable amount of electricity from solar pv, coal based thermal power plants still hold a major share (87%) in power generation. The current power generation from coal based thermal power plants is 194445 MWe (134388 MWe in 2014) Table 1. Renewable based power generation also registered an increase of 9% compared to 2014 generation status. Overall annual growth in electricity generation has not drastically changed from that reported in 2014. Besides coal, rice paddies and cattle are also major sources of emissions.

In the India context, it is difficult to control the last two sources of emitters. In spite of this increase in electricity generation, 13 % of the Indian population have no access to electricity and rely on traditional sources of energy such as dung, wood, for their domestic needs. Although few villages have been given electricity through solar pv, the quality of electricity is not satisfactory (https://www.carbonbrief.org/the-carbon-brief-profile-india. Accessed on 2 July 2019). India's per capita emissions stood at 2.7 t CO_2 in 2015, while the global average emissions are 7t (tonnes) CO_2 in the same year (Oliver et al., 2017, https://www.carbonbrief.org/the-carbon-brief-profile-india. Accessed on 2 July 2019). Multi regional global energy system model (TIAM-UCL; Anandarajah and Gambhir, 2014) indicate that India can achieve per-capita CO_2 emissions of 1.3 t by 2050 by adopting low carbon renewable energy sources. Similarly, according to LEAP model (Kumar and Madlener, 2016), under the accelerated renewable technology scenario, by 2050 India will be in a position to reduce emissions up to 74%, by increase the use of renewable energy by 36%. The Black Carbon (BC) emissions over India during the year 2018 was 2534 Gg/y (Verma et. al., 2017) which is twice the value reported during 2008 1343 Gm/y ((Sahu et al., 2008, Chandrasekharam and Chandrasekhar, 2015). Considering the emissions reported during the lifecycle of solar pv (Chandrasekharam and Ranjith, 2019), geothermal is better option compared to other renewables in controlling the global CO_2 emissions and keep check on the global temperature rise. Although slow, the geothermal energy is making tremendous progress in India with new discoveries and new applications. The setback in the development is mainly due to lack of policy for geothermal. Ministry of New and Renewable Energy has circulated draft policy report which is being revised based on the comments from members of the International Geothermal Association, Germany.

Table 1. India's Power generation status: 2018 (MoP, 2018)

2018 status

- **Present Production:** 3,56,818 MWe
- **IPP's contribution:** (1,47,125) MWe

Plant/Fuel Type		MWe		Percentage	
Thermal		2,26279		(64)	
	Coal		194445		87
	Gas		24937		11
	Oil		638		2
Hydro		45399		13	
Nuclear		6780		2	
Renewable		78359		21	
Total		356818		100	

- Expected (addition) Production by 2017-18: 200000 MWe
- Growth in : 2015-16 5.6%
- Growth in 2016-17 4.7%
- Growth in 2017-18 3.95

Ministry of Power
Annual report 2018

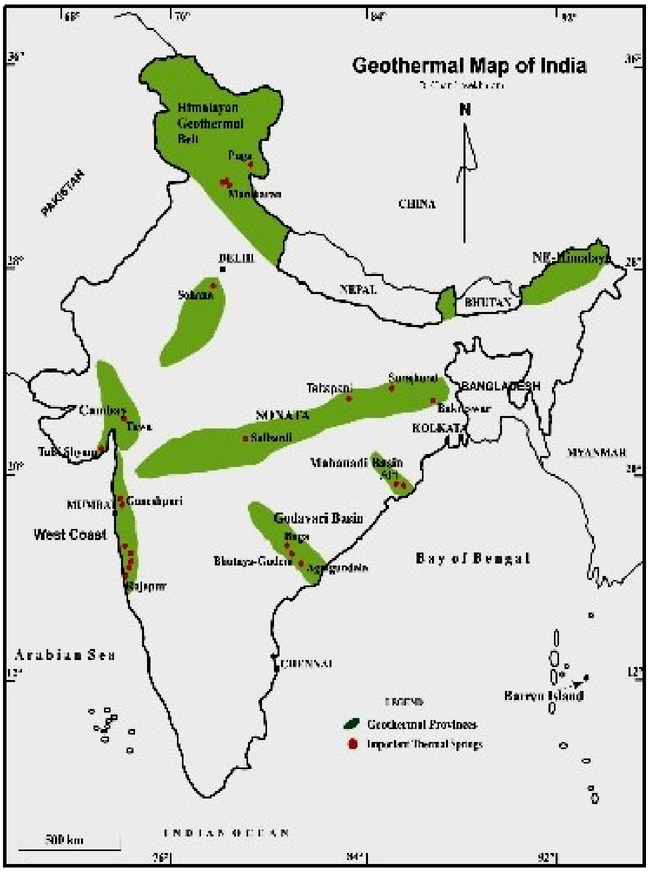

Figure 1: Geothermal provinces of India

2. EXPLORATION ACTIVITIES

Exploration work is being carried out in several geothermal provinces by government and private institutes. These are elaborated in the following section.

2.1 West coast thermal province

Boron isotopic concentration (2.5‰ to 27.0‰) and REE concentration in the thermal waters of Rajapur, West Coast geothermal province (Figure 1) was published recently (Trupti et al., 2016, a,b, 2018). This is the first-time boron isotopes and REE content were utilized to understand the evolution of the thermal springs in India. The data indicate presence of thick sedimentary layer below the Deccan Trap flow overlying the basement granite. The thermal fluids are circulating through the granites and the sedimentary layers before emerging to the surface. This data together with water-rock interaction experimental work (Trupti et al, 2018; Trupti et al., 2016 a,b,c) suggest reservoir temperatures of the order of 260 °C for these thermal springs.

2.2 Gujarat geothermal province

Tulsi Shyam thermal springs in Gujarat geothermal Province (Figure 1) (Minissale et al., 2003) are visited again with additional geothermal heat flow data to understand their evolution (Singh et al., 2018). These springs are located in the Saurashtra region of Gujarat, India with discharge temperatures varying from 39 to 42 °C. Though these thermal springs emerge through the near surface layer of Deccan basalt, detailed geochemical analysis suggests that the waters are interacting with the granitic basement rock. Silica and cation geothermometry estimates have reservoir temperature in the range of 138 to 207 °C. Furthermore, the area has high heat flow values of 53–90 mW/m^2 because of shallow Moho depth. The prevailing conditions suggest that this site is a potential EGS site for future exploration activities (Singh et al., 2018).

2.3 Bihar-Bengal geothermal province

Geothermal springs in this province discharge considerable amount of helium (He) as described earlier during the previous world geothermal congress in Australia (Chaudhuri et al., 2015). A review on the helium emissions from all the geothermal springs has been carried out. Although helium is a major ingredient in the gases from all the thermal springs, the concentration of helium in Bakreswar thermal springs in Bihar-Bengal geothermal province is anomalously high encouraging recovery of helium from the thermal springs. A pilot helium recovery plants has been established about 5 years ago and is working successfully (Chaudhuri et al., 2019).

2.4 Jharkhand geothermal province, Eastern India

New data on the thermal springs occurring in Jharkhand in Eastern Peninsular India have been presented (Singh et al, 2019..this volume). The geothermal waters have relatively higher concentration of Na^+, and K^+ as compared to those of Ca^{++} and Mg^{++}; Cl^- and SO_4^{--} are in reasonably high concentration compared to concentration of HCO_3^- and CO_3^{--}. Fluoride concentration in the geothermal waters is significantly high (18.8 to 24.9 mg/L). High concentration of Cl^- and F^- in thermal springs is postulated to be due to deep circulation of waters within the granitic basement. The heat generating capacity of the granites have been calculated based on uranium, thorium and potassium content in the granites exposed on the surface as well as granites cores taken from drill holes in this area. This varies from 71.3 – 142.8 mW/m^2. These high heat producing granites are probable heat source for these thermal springs.

2.5 Himalayan geothermal province

Carbon isotopic and oxygen and hydrogen isotopic data on the thermal springs from Indus, Nubra valley, Sutlej, Beas and Parbati valleys falling within the Himalayan geothermal provinces (Figure 1) have been published (Tiwari et al., 2016). The authors utilized the carbon isotope ratios to understand the evolution of the thermal's springs. The δ^{13}CDIC ratios of these springs vary from −8.4‰ to +1.7‰VPDB, indicating a deeper source of their origin of CO_2 (CO_2 flux from metamorphic reactions in the continental crust) in the thermal waters. Their study indicates that the NW Himalayan geothermal province has the potential to degas 2.9 x 107 mol CO_2 per year. Further they report reservoir temperature of 107 °C. Thus, this province is a potential source of natural CO_2 emissions.

2.6 Exploration drilling

The Geological Survey of India drilled four exploratory bore wells within the Godavari geothermal province (Figure 1). Hot water with temperatures varying from 67 to 82 °C, with flow rate of 20 30 L / second discharges from these wells (Figure 2). These wells are best suited for power generation by installing 2 to 3 MWe well head generators.

Figure 2: Exploratory bore wells in Godavari valley.

3. HIGH HEAT GENERATING GRANITES

Assessment of (geochemical and physio-mechanical properties) potential granites and granite provinces suitable for initiating EGS (Enhanced Geothermal Systems) projects is being continued in different regions of the country. High heat generating granites are exposed through the country and initial assessment on the heat generation status and heat flow values over these granite from several parts have already been reported (Chandrasekharam et al., 2007, 2008 a, b, 2010, 2014 a, Singh et al., 2014b, Singh et al., 2015 a, b). This work is being continued. Last two years heat generation capacity of granites and heat flow values over the terrain has been assessed. The results are reported in this congress (Chandrasekharam et al., 2020)

4. NEW DEVELOPMENTS

Private commercial establishments are keen in installing GHP for space cooling to save large electricity bills. For the first time 72 KWe GHP unit was installed, by M/S GeoSyndicate Power Pvt. Ltd., in a pharmaceutical storage house, in Mumbai, India, using groundwater drawn from a well as a circulating medium. A shell and tube exchanger (Figure 3) were used to maintain the

Figure 3: GHP unit installed in a pharmaceutical storage facility.

space temperature of 27 °C. The unit is running successfully since installation in March 2019. This has brought awareness amongst several commercial establishments and M/S GeoSyndicate has received several orders from food and grains storage establishments to installed space cooling units. This is good sign of development for saving electricity generated from fossil fuel and saving considerable CO_2 emissions. Recently Ministry of New and Renewable Energy, Govt. of India expressed interested in encourage GHP technology in public and private establishments and is drafting a geothermal energy policy document to be implemented in India soon.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		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	0		226,279	1,585,763	45,399	318,156	6,780	56,423	78359*	205,924	356,818	2,166,266
Under construction in December 2019	25	197	11,366	79,652	1,305	9,145	500	4,161	120	315	13,291	93,470
Funds committed, but not yet under construction in December 2019	25	197	11,366	79,652	1,305	9,145	500	4,161	120	315	13,291	93,470
Estimated total projected use by 2020	25	197	237,645	1,665,415	46,704	327,301	7,280	60,584	78,479	206,239	370,109	2,259,736

* includes small amount of wind, biomass and small hydro Source: MoP, 2018

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2019

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Electrical installed capacity in 2019

4) Electrical capacity actually up and running in 2019

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1]	Type of Unit[2]	Total Installed Capacity MWe[3]	Total Running Capacity MWe[4]	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
Total									

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (other than heat pumps)

1) I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Himalayas	B,O	1000[a]	95	15			118.7	100	1055.2	0.3
Cambay	B	1200[b]	85	25			106.8	80	633.1	0.2
West Coast	B	160[c]	72	30			10.0	10	55.4	0.2
SONATA	B	100[d]	95	25			10.4	13	120.0	0.4
Bakreswar	B	600[e]	89	30			52.5	100	778.2	0.5
Jharkhand	B	400[f]	89	25			38.0	63	531.8	0.4
Bihar	B	360[g]	50	25			13.4	72	237.4	0.6
Godavari										
Manuguru 1	O	25[h]	82	30			5.4	25	171.5	1.0
Manuguru 2	O	25[h]	71	30			4.2	25	135.2	1.0
Manuguru 3	O	25[h]	67	30			3.7	25	122.0	1.0
Manuguru 4	O	25[h]	80	30			5.1	25	164.9	1.0
							368.2	513	4004.7	6.6
TOTAL							357.5	538	4004.7	12.2

O: Cooking
a: cumulative discharge of 10springs
b: cumulative discharge of 15 springs
c: cumulative discharge of 16 springs
d: cumulative discharge from 6 springs
e: cumulative discharge from 6 springs
f: cumulative discharge from 6 springs
g: cumulative discharge of 5 springs
h:discharge from single bore-well

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the rejected to the ground in the cooling mode as this reduces the effect of global warming.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

3) Report the COP = (output thermal energy/input energy of compressor) for your climate - typically 3 to 4

4) Report the equivalent full load operating hours per year, or = capacity factor x 8760

5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

6) Cooling energy = rated output energy (kJ/hr) x [(EER - 1)/EER] x equivalent full load hours/yr

Note: please report all numbers to three significant figures
Due to room limitation, locality can be by regions within the country.

Locality	Ground or Water Temp. (°C)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year[4]	Thermal Energy Used[5] (TJ/yr)	Cooling Energy[6] (TJ/yr)
Mulund Mumbai India	27	72	2	W	5.9	7884	3.8251	2.3742
TOTAL								

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

[1] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[2] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.131 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[3] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W
since projects do not operate at 100% capacity all year

[4] Other than heat pumps

[5] Includes drying or dehydration of grains, fruits and vegetables

[6] Excludes agricultural drying and dehydration

[7] Includes balneology

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]			
Air Conditioning (Cooling)	0.144*	3.82	0.8
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	357.5	4004	0.3
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps			
TOTAL	357.6	4007.82	1.1

* total of two units

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)

[1] Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)				4	1km
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total					4	1km

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

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Prograr
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	2	nil	20	nil	nil	25
2016	1	nil	30	nil	nil	20
2017	2	nil	35	nil	nil	20
2018	3	nil	40	nil	nil	20
2019	3	nil	40	nil	nil	20
Total	11		165			125

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

Period	Research & Development Incl.	Field Development Including Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	0.022	nil	0.00816			100
2000-2004	0.133	nil	0.0122		70	30
2005-2009	0.503	nil	0.0321		75	25
2010-2014	15	5	0.5		100	0
2015-2019	150	80	15		80	20