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An Update on the Philippine Geothermal Resource Estimates

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ABSTRACT

An updated estimate was made for the Philippine geothermal reserves and resources using stored-heat method with Monte Carlo simulation. The results of the computation suggest that the Philippine geothermal resources ranges from 1,028MWe (P90) to 4,064MWe (P10) with 2,152 (P50) as the best estimate. Likewise, this paper has counted approximately 136 geothermal areas that includes the 8 areas currently in commercial operation. This paper showed significant increase in the resources estimates compared to the 2010 values. The reason can be linked to additional data that has been generated for the past decade. With the onset of enabling policies, advances in technology, and DOEs continuing initiative of preliminary surveys of the country's geothermal resources, the further development of the remaining geothermal resources may now be realized in the coming years.

1. INTRODUCTION

This paper follows the report of Pastor et. al. (2010) on the estimated potential capacities of geothermal reserves and resources in the Philippines. The only difference used between the 2010 report with this is the use of updated information as well as the Monte Carlo simulation on the stored heat method with the use of the commercially available @Risk software.

The total resource potential of the country's geothermal resources is estimated to be around ±4,000 MWe. With the existing installed capacity of 1,918 MWe, there are still at least 50% of the geothermal resources left for development. Along with the updating of the resource estimates, this paper has also updated the list of the geothermal areas and further categorized it between high and low-medium temperature resources for easier identification of applicable technology to be used if developed.

Figure 1 shows the location of the country's geothermal resources. The map also shows the geologic setting from which the geothermal resources are associated. As observed in Malapitan and Reyes (2000), the Philippines geothermal systems are located and related to areas with volcanism (Quaternary to Recent) with dense faulting.

2. STORED HEAT METHODOLOGY

The development and utilization of geothermal resources starts with the identification of key indicators that suggests an area has the potential for power generation. For this, Geoscientific studies comprising of geological, geochemical and geophysical surveys are conducted. If the results of the Geoscientific studies or 3G (geology, geochemistry and geophysics) are attractive, exploratory drilling follows for confirmation of the potential resource. From here, the quantifiable thermal energy that can be tapped and utilized economically for a specified time is called resource assessment (Sarmiento & Steingrimsson, 2011). Sanyal and Sarmiento (2005) further categorized the methodologies of resource assessment; 1) areas with no production data and 2) areas with production data. The methodology most applicable for areas with no production data is the stored heat method while it the most common method is numerical simulation for areas with production data.

Under methodologies that require no production data, the stored heat method is the most applicable for areas with 3G data. However, it should be noted that the computed value is highly dependent on the input variables, therefore these variables should be based on reasonable data. With this, there are conflicting discussions on the outcomes from the use of the stored heat method. Sanyal and Sarmiento (2005) discussed that it is prone to overestimation, while other authors states that it may be conservative since resupply or recharge is neglected (Muffler & Cataldi, 1978), (Australian Geothermal Energy Group, 2010). Zarrouk and Simiyu (2013) suggests the addition of natural thermal output if significant. Even with these reasons, stored heat will still be the preferred method for this paper.

The stored heat method or the volumetric method is determined from the computation of the recoverable "stored heat" or thermal energy from the combination of rock and water in a disclosed volume. The theoretical maximum quantity of useful heat, H_{th} (Equation (1)) which is available for utilization, taken from (2013):

$$Hth = A * h\{[(1-\varphi)\rho rcr(Ti - Tf)] + \varphi\,[\rho vSv\,(hvi - hvf) + \rho lSl\,(hli - hlf) - (Psi - Psf)]\} \quad (1)$$

where:

Φ = porosity
ρ_l and ρ_v = densities of the liquid and vapor phases
S_l and S_v = liquid and vapor saturations (volume fractions, $S_l + S_v = 1$)
ρ_r = rock density (kg/m^3)
c_r = rock specific heat (J/kg K)
h = enthalpy (kJ/kg)
P = saturation pressure at given reservoir temperature

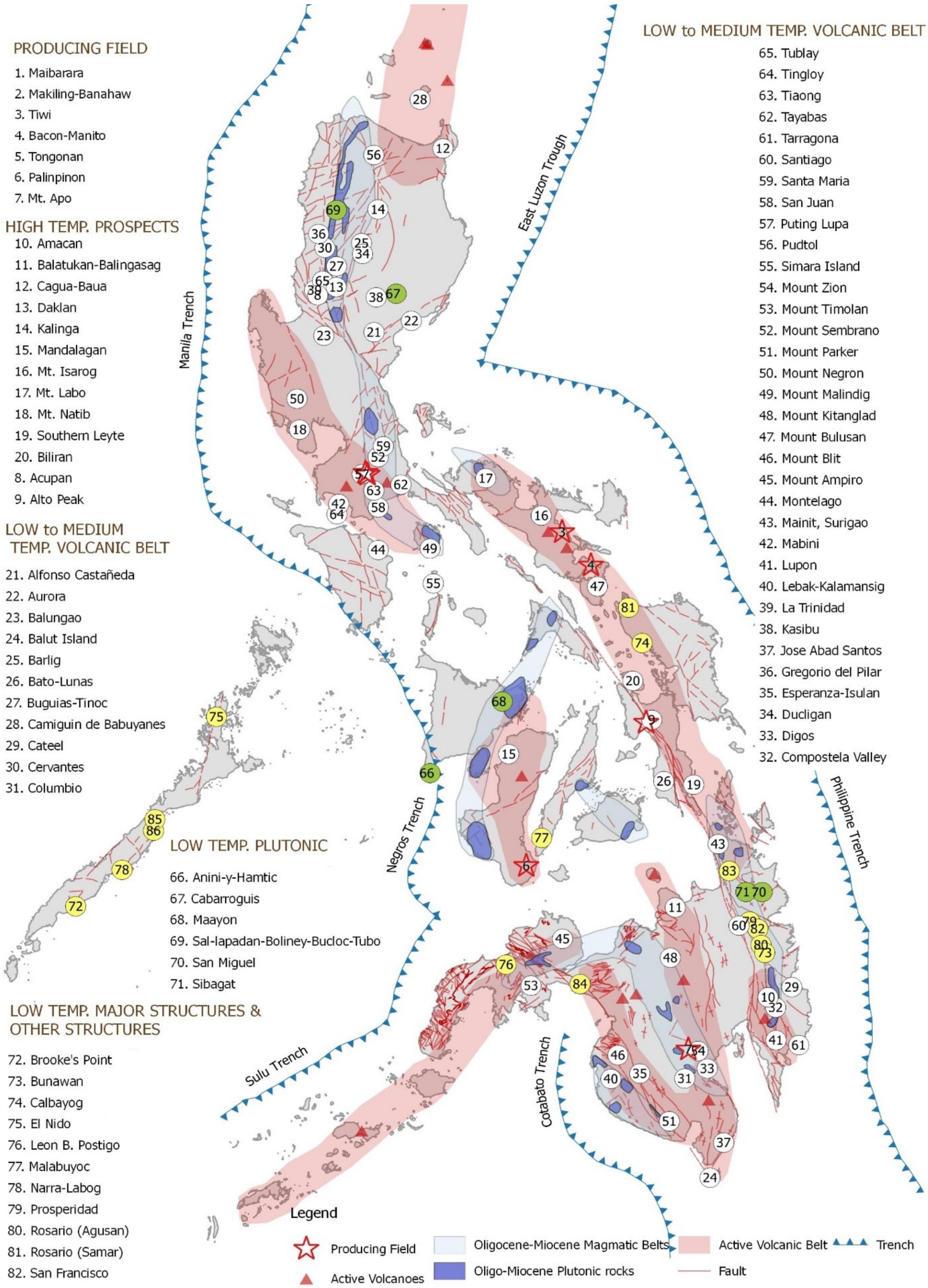

Figure 1: Location map of the distribution of the Philippines geothermal resources. The circles colored green, white and yellow represents the geothermal areas that are associated with plutonic occurrences, volcanic belt and non-active structures, respectively.

The power plant capacity can then be calculated from:

$$We = \frac{(Hth*Rf*\eta c)}{(L*F)} \tag{2}$$

where:

R_f = recovery factor
η_c = conversion efficiency
L = power plant life, seconds
F = power plant factor

From this methodology, it is evident that the result of such computation is heavily dependent on the given reservoir geometry and the recovery factor assigned.

2.1 Selection of Parameters

As can be seen from Equations 1 and 2, the parameters on reservoir geometry, reservoir temperature, rejection temperature, fluid and rock properties, recovery factor, conversion efficiency, power plant factor, and plant life are the variables for the computation of the resource potential. This information is both taken from measurements, estimates and analogies.

2.1.1 Areal extent

The areal extent of the reservoir is usually taken from the results of resistivity survey where the results show the conductive layer. This conductive layer is the formation of cap rock that serves to contain the geothermal fluid. The bottom of this conductive layer is usually measured as the area of the reservoir.

In this report, sources of the areal extent used come from the resistivity anomalies, temperature contours generated from the submitted reports of the RE Developers and from Pastor's (2003) report on Philippine geothermal energy resource estimates. As discussed by Pastor, some of the estimated areal extent in the report comes from the distribution of thermal manifestations while some of the resistivity data comes only at a minimum to maximum figures while others are one value, assumed as the maximum extent. On this situation, the author takes the average of the minimum and maximum area as the most likely area. On other cases where the geothermal field has demonstrated low permeability, although new geophysical surveys has been conducted, the minimum value is assigned as zero (0) to represent the possibility that low permeability may still be expected all throughout the reservoir.

2.1.2 Reservoir thickness

Thickness refers to the mean thickness of the reservoir taken from the upper coverage of 260°C temperature contour up to the bottom of the producing well. But as discussed by Sarmiento and Steingrimsson (2011) the temperature range can still be lowered to 240°C and an additional 500m may still be added to the total length of the well. In cases that information on such reservoir thickness is not available, the author assigns the arbitrary values of 1,500m as the most likely, minimum and maximum values as 1000 and 2000m respectively.

2.1.3 Reservoir rock properties

Rock porosity is defined as the ratio of the volume of pore space to the volume of the system (O' Sullivan 2013). It is also defined as the flow porosity or void space in SKM 2002 referred in Zarrouk (2013). Further, it is difficult to measure the porosity in geothermal reservoirs because of their fractured nature, which may not be captured by core samples. However, based on reservoir simulations, reasonable estimate of reservoir rock porosity (effective porosity) ranges from 0.1 to 0.3. Lastly, porosity has a small impact on overall stored heat, but the effective flow porosity of rock is strongly related to permeability of the reservoir; which in turn can effectively influence recovery factor.

Rock density is a measure of the ratio mass/volume of the material. Rock density should be measured from representative rock samples, however, if for a Greenfield where no measured data is available Zarrouk (2013) suggests to use the correlation by Vosteen and Schellschmidt, 2003. The same is also true for the selection of *rock specific heat* values.

In this report, the default porosity of 5% and 8% as the minimum and maximum values are assumed on geothermal fields without readily available porosity value. Likewise, rock specific heat values of 900 J/kg.K and rock density of 2700 kg/m^3 were used.

2.1.4 Reservoir temperature

Reservoir temperature is taken from direct downhole measurements on wells and estimates from geothermometry.

Again, in this report the reservoir temperatures were taken from the submitted technical reports of Developers and Pastor's (2003) report. An average value of the minimum and maximum values was assumed as the most likely reservoir temp. For the base temperature or rejection temperature, a default value of 180°C was used for high-temperature geothermal resources and 80°C was used for low-medium temperature resources. The selection of this abandonment temperature is dependent on the most likely reservoir temp. The reservoir temperature is also the basis from which the thermodynamic properties of the reservoir fluids are based.

2.1.5 Recovery factor, conversion factor, plant factor and plant life

The use of recovery factor, conversion factor, plant factor and plant life are necessary for the complete conversion of the stored heat to resource capacity. *Recovery factor* is defined as the ratio of extracted thermal energy (measured at the wellhead) to the total geothermal energy contained in a given subsurface volume of rock and water (Muffler and Cataldi 1978).

As compiled by Zarrouk and Simiyu (2013), a wide range (8% to 30%) of recovery factors is used by several authors in their stored heat assessment. However, no solid justification is provided, therefore the selection of appropriate recovery factor is upon the discretion of the author. As discussed in Grant (2014), Sanyal et. al. (2002) found factors of 5-10% were a more reasonable range of recovery factor values. In the same context, Sanyal et. al. reviewed the USGS assessments and found that the total resource was one-third of the original estimate, and that the recovery factors should lie in the range 3-17% with a mean of 11%. Lastly in the same paper, Grant suggests an average value of 10% should be used as it corresponds to observed results. Meanwhile, Muffler and Cataldi (1978) proposed that the recovery factor is linearly dependent on field porosity. This is also represented by the empirical equation:

$$Rf = 2.5 * \varphi \tag{3}$$

This report will apply Equation (3) for the most likely recovery factor with 3% and 17% as the minimum and maximum values, respectively. However, for other areas that has high porosity values, the maximum value assigned is 25%, consistent with the findings in Grant (2014) that the Philippine stored heat computation which is based on the abandonment temperature of the well rather than the turbine, would still have acceptable results as demonstrated in the works of Sarmiento and Bjornsson (2014).

Conversion factor or conversion efficiency is the ratio of net electric power generated (MWe) to the geothermal heat produced (MWth) from the reservoir. There are several correlations made between the conversion efficiency and the reservoir temperature or reservoir enthalpy based on all of the energy removed from the resource (Zarrouk 2013). On the other hand, Zarrouk and Moon (2014) recommends the correlation of conversion efficiency to enthalpy (Equation (4)) to be used if considering a generic conversion.

This report will use Equation (4) for conversion efficiency:

$$\eta c = 7.8795 \ln(h) - 45.651 \tag{4}$$

Power plant load factor is a combination of plant availability for generation and ratio of actual output to its optimum operation design for certain production time (*plant life*). A most likely value of 90%, 85% minimum and 95% maximum are used for in this report as well as a 25 years plant life.

2.1.6 Summary of parameters

Table 1 shows the summary of the parameters used for the computation of the resource & reserve capacities of Philippine geothermal resources.

Table 1: Summary of the parameters used in the stored heat computation.

Parameters	**Value**	**Remarks**	**PDF**
Area (km^2)	Variable	Resistivity anomaly, temp. contour.	Triangular
Thickness (m)	Variable	A default value of 1,500, 1000 and 2000 as the most likely, min and max values were used	Triangular
Reservoir temp. (°C)	Variable	Measured or geothermometers	Triangular
Rejection temp. (°C)	180, 80	180 for high temp and 80 for low to medium temp. resources	
Rock density (kg/m^3)	2700	Fixed	
Rock specific heat (J/kg.K)	900	Fixed	
Rock porosity (%)	Variable	A default value of 5% is used in areas with no available data	lognorm
Reservoir fluids	Variable	Function of temp.	
Fluid saturation	1	Assume liquid dominated reservoir	
Recovery factor (%)	2.5 * porosity	Function of porosity	Triangular
Conversion factor (%)	$7.8795 \ln(h) - 45.651$	Function of enthalpy	
Plant factor (%)	90%, 85%, 95%	Fixed values. Most likely, minimum and maximum values	Triangular
Plant life (years)	25	Fixed	

2.1.7 Monte Carlo simulation

This method relies on a specified probability distribution of each of the input variables and generates an estimate of the overall uncertainty in the prediction due to all uncertainties in the variables (Kalos, 2008). For estimating geothermal production capacity, this method is applied to the parameters of the volumetric stored heat equation where the parameters are allowed to vary over a range of values and within a defined probability distribution function (PDF) (Lawless 2007). Also in Table 1, the PDFs assigned in the parameters for the Monte Carlo simulation are shown. The simulation was done with the used of the commercially available excel add-in software @Risk by Palisade Corp. (n.d.).

3. RESOURCE CLASSIFICATION

The classifications for the Philippine geothermal resources are based on two aspects: 1st is based on available data and 2nd is the distinction based on estimated reservoir temperature. Such classification will enable the DOE and interested developers in selecting the best or appropriate development scheme for a particular geothermal field.

3.1 Resource and reserves

Muffler and Cataldi (1978) proposed a logical and sequential distinction of a geothermal base. It identified that the resource part that is shallow enough to be tapped by production drilling is termed as the accessible resource base. The accessible resource base is further divided into useful and residual components, where the useful part is called geothermal resource. This geothermal resource is then divided into economic and sub-economic modes. The economic category refers to the energy that can be extracted legally and competitive with other energy sources at the time of determination while the sub-economic part is the energy that cannot be extracted legally, even at current competitive with other sources of energy, but could be utilized in the future. In the corresponding illustration identified in the same paper, it illustrates the economics of the geothermal base, based on the degree of geologic assurance. Here, resource is defined as the useful accessible resource base while reserve is the part that is identified (drilling, geological, geochemical and geophysics) and is economical. For further definitions of the resource and reserve, the work of Sarmiento and Steingrimsson (2011) will be adapted.

3.1.1 Reserves

Reserves are defined as quantities of thermal energy that are anticipated to be recovered from known reservoirs from a given date forward. A reserve is the part of the resources, which can be extracted economically and legally at present and that is known and characterized by drilling or by geochemical, geophysical and geological evidence.

a. Proven

Proven reserves are quantities of heat that can be estimated with reasonable certainty based on geoscientific and engineering data to be commercially recoverable from the present to the future, from known reservoirs under economic conditions and operating methods and government regulations.

b. Probable

Probable reserves are unproven reserves which are mostly likely recoverable, but are less reliably defined than the proven reserves but with sufficient indicators of reservoir temperatures from nearby wells of from geothermometers on natural surface discharges to characterize resource temperature and chemistry.

c. Possible

Possible reserves have slighter chance of recovery than the probable reserves but have sound basis from surface exploration, such as springs, fumaroles, resistivity anomalies, etc., to declare that a reservoir may exist.

3.1.2 Undiscovered Resources

Undiscovered Resources in this report pertains to geothermal fields that are identified only by geological and geochemical surveys that need further assessment as well has inconclusive geophysical data.

3.2 Reservoir temperature

Classification under estimated reservoir temperature is now introduced in this report. The previous estimates have not explicitly identified the distinction of geothermal reserves and resources based on reservoir temperature. It is the author's belief that recent technological advances have allowed the development and commercialization of the previous "unattractive" low to intermediate temperature geothermal resources. There are now binary or ORC systems that are available with commercial installations around the world.

The classification of geothermal resources based on reservoir temperature is taken from Dickson and Fanelli (2003) and follows the distinction of Hocstein, as follows:

Low enthalpy resources:	<125°C
Intermediate enthalpy resources:	125-225°C
High enthalpy resources:	>225°C

4. RESULTS AND DISCUSSION

The objective of this paper is to update the estimated capacities, with the use of the Monte Carlo simulation, of Philippine geothermal reserves and resources with new technical data gathered from both internal studies and reports from developers. The result of the Monte Carlo simulation shows the range of resource capacity estimates of a particular geothermal field. The values from P90 represents the minimum, median values for P50 and maximum values for P10. The mode was also computed and represents the most likely values.

The total identified geothermal resources of the Philippines ranges from 1,028 MWe (P90) to 4,063 MWe (P10), with the best estimates at 2,152 MWe (P50). Comparing the results from the 2010 estimates with the P10 estimates in this paper shows an increase from 3,377 to 4,063 MWe. The difference can be deduced from the new sources of information and data used in this paper.

Aside from the updated capacity estimates, the number of geothermal areas was also updated. There is a total of 136 geothermal areas that are identified under this paper. As shown in Figure 2 and Table 2, the bulk of geothermal areas are still open for development. Table 3 is the summary of the resource estimates made for this paper. However, since there are still insufficient data to definitely categorize these areas, this number may still change as the DOE continues its studies. Further, it is common knowledge that stored heat estimates does not necessarily translate to installed capacities; take the Northern Negros geothermal project and other geothermal developments with permeability problems as examples.

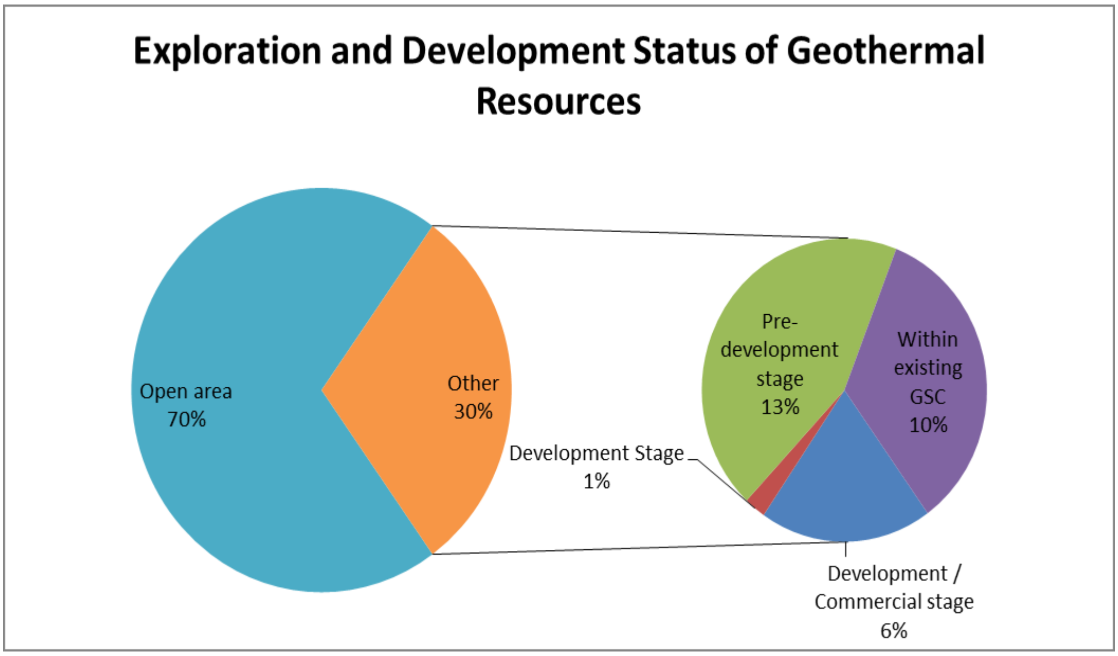

Figure 2: Exploration and development status of geothermal resources. A significant number of these geothermal areas are still open for development while the rest are under various stages of exploration and development.

Table 2: Status of exploration and development of the Philippines geothermal reserves and resources.

Row Labels	NUMBER of GEOTHERMAL FIELD	INSTALLED CAPACITY (MWe)	P90 (MWe)	Mode (MWe)	P50 (MWe)	P10 (MWe)
Development / Commercial stage	8	1918.22	672.722	997.656	1337.186	2588.044
Development Stage	1	0	21.178	38.91	36.545	50.197
Pre-development stage	18	0	188.425	378.309	461.728	855.015
Within existing GSC	14	0	71.872	133.23	155.494	283.931
Open area	95	0	74.244	132.29	161.069	286.684
Grand Total	**136**	**1918.22**	**1028.441**	**1680.395**	**2152.022**	**4063.871**

Table 3: Summary of revised estimated resource capacities.

RESOURCE CATEGORY	CLASSIFICATION BASED ON TEMP.	GEOLOGICAL SETTING	GEOTHERMAL FIELD	INSTALLED CAPACITY (MWe)	P90 RESOURCE CAPACTITY (MWe)	Mode RESOURCE CAPACITY (MWe)	P50 RESOURCE CAPACITY (MWe)	P10 RESOURCE CAPACITY (MWe)
Proven Reserve	High Temperature System	Bicol – Mindanao Central Cordillera Volcanic Belt	Tongonan (Leyte) Geothermal Production Field	722.68	208.49	286.18	397.56	667.71
			Tiwi Geothermal Field	234	92.77	139.48	183.91	574.92
			Bacon-Manito Geothermal Production Field	140	65.86	104.52	114.04	163.77

			Alto Peak Geothermal Prospect	0	4.845	11.22	11.483	24.286
			Bacman 3 (Tanawon) BGPF expansion sector	0	6.957	12.136	12.095	17.46
			Biliran 1 Geothermal Project	0	69.44	116.85	124.77	187.33
		Central Mindanao – Cotabato Volcanic Belt	Mt. Apo Geothermal Production Field	108.48	26.26	44.841	45.772	67.335
			Mindanao 3 MGPF expansion sector	0	9.396	14.937	20.516	39.658
		Negros - Sulu Volcanic Belt	Southern Negros Geothermal Production Field	222.5	115.84	183.48	217.83	341.79
			Northern Negros Geothermal Production Field	0	21.178	38.91	36.545	50.197
		Santa Ana - Luzon Central Cordillera - Central Luzon - Cuyo Volcanic Belt	MakBan Geothermal Field	458.56	85.54	111.46	234.96	552.369
			Maibarara Geothermal Project	32	8.522	10.845	18.344	32.82
	Intermediate Temperature System	Bicol – Mindanao Central Cordillera Volcanic Belt	Bacman (Manito Lowlands) BGPF expansion sector	0	12.133	23.372	22.813	36.187
Probable Reserve	High Temperature System	Bicol – Mindanao Central Cordillera Volcanic Belt	Amacan Geothermal Prospect	0	4	19.9	24.36	50.58
			Bacman 4 (Botong-Rangas / East Bacman) BGPF expansion sector	0	7.434	13.531	15.951	30.656
			Burauen LGPF expansion sector	0	4.913	10.366	13.154	26.496
			Mt. Labo Geothermal Prospect	0	13.69	20.48	28.74	51.97
			Southern Leyte Geothermal Prospect	0	12.753	19.987	25.42	42.827
		Negros - Sulu Volcanic Belt	Dauin SNGPF expansion sector	0	12.994	19.454	24.1	38.225
		Santa Ana - Luzon Central Cordillera - Central Luzon - Cuyo Volcanic Belt	Acupan-Itogon Geothermal Prospect	0	5.25	8.537	9.036	13.377
			Cagua-Baua Geothermal Project	0	50.76	106.62	125.2	230.65
			Daklan Geothermal Project	0	14.111	23.004	26.544	44.106
			Kalinga Geothermal Project	0	22.69	43.21	41.74	67.09

			Mt. Natib Geothermal Project	0	12.375	20.103	21.855	33.031
	Intermediate Temperature System	Santa Ana - Luzon Central Cordillera - Central Luzon - Cuyo Volcanic Belt	Montelago Geothermal Project	0	8.419	14.764	16.482	26.971
			Mt. Puting Lupa Geothermal Project	0	6.163	9.642	16.48	34.778
			Tayabas-Lucban Geothermal Project	0	9.542	18.349	23.738	41.672
Possible Reserve	High Temperature System	Bicol – Mindanao Central Cordillera Volcanic Belt	Bacman 5 (Kayabon / West Bacman) BGPF Expansion Sector	0	7.755	18.934	21.287	44.455
			Biliran 2 Geothermal Project	0	21.36	49.47	53.46	96.1
			Mt. Isarog Geothermal Prospect	0	9.473	18.554	24.186	45.11
	Intermediate Temperature System	Bicol – Mindanao Central Cordillera Volcanic Belt	Bato-Lunas LGPF expansion sector	0	5.445	9.28	14.095	26.508
			Southern Bicol (Mt. Bulusan Complex) Geothermal Project	0	25.45	46.77	65.1	128
		Central Mindanao – Cotabato Volcanic Belt	Balut Island Geothermal Prospect	0	6.675	16.53	17.374	33.018
		Negros - Sulu Volcanic Belt	Mt. Ampiro Geothermal Project	0	9.23	19.82	24.71	49.9
			Mt. Timolan (Lakewood) Geothermal Project	0	3.44	5.262	8.624	16.172
		Santa Ana - Luzon Central Cordillera - Central Luzon - Cuyo Volcanic Belt	Cervantes Geothermal Project	0	0	0	0	0
			Mabini Geothermal Project	0	5.188	11.007	13.028	24.257
			Tiaong Geothermal Project	0	22.1	38.59	56.72	112.09
		Along major structures and other structures	Sta. Lourdes-Tagburos Geothermal Prospect	0	0	0	0	0
	Low Temperature System	Along major structures and other structures	El Nido Geothermal Prospect	0	0	0	0	0
			Malabuyoc Geothermal Prospect	0	0	0	0	0
			Sta. Lucia-Iwahig Geothermal Prospect	0	0	0	0	0
Grand Total				1918.22	1028.441	1680.395	2152.022	4063.871

5. CONCLUSION

There are still a substantial number of geothermal areas left for further studies. Recent development has shown that there are previously undiscovered geothermal area that is actually a high temperature resource and is therefore attractive for development. This just shows that the 95 geothermal areas open for development may still host high temperature resources. But this does not necessarily mean that low-medium temperature geothermal areas are not attractive. Commercial installations around the world shows modular capacities are put on-line and may be adopted also in the country. To support this, the DOE is coming-up with a review of existing technologies and installations that will serve as a centralized reference.

Furthermore, the government recognizes the challenges in the development of geothermal resources, among other energy projects. In line with this, several policies and laws has been enacted: one is the Executive Order no. 30, which aims to streamline the process for permits acquisition, the Republic Act no. 11234 or the Energy Virtual One-Stop Shop, which acts as an online platform where developers can apply, monitor and even pay for the acquisition of permits from various government agencies; and lastly the Republic Act no. no. 11032 or the Ease of Doing Business and Efficient Government Service Delivery Act of 2018 which aims to shorten the transaction periods for permits acquisition. All of the mentioned policies will cut the transaction periods and promote greater transparency with regard to the permits required in setting up an energy project. In addition, under the implementing rules of the Renewable Energy Law, the Renewable Portfolio Standards, mandates Distribution Utilities to source-out a percentage of their generation or energy distribution from eligible Renewable Energy resources, such as geothermal energy. Likewise the Green Energy Option empowers the consumers in selecting the preferred source of power from Renewable Energy resources.

There are still a great number of geothermal resources left for development. With the onset of enabling policies, advances in technology, and DOEs continuing initiative of preliminary surveys of the country's geothermal resources, the further development of the remaining geothermal resources may now be realized in the coming years.

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