RANKING OF INDONESIAN GEOTHERMAL PROSPECTS (KNOWN RESERVES)

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ABSTRACT

Ranking of explored Indonesian geothermal prospects provides realistic estimates for ongoing and planned development of prospects suitable for economic production of electric power. Ranking starts with a classification of prospects allowing for quality of exploration data and status of exploratory drilling. The potential of 57 explored and partly developed Indonesian geothermal prospects (2010/11 status) was assessed by dividing them into: developed and producing fields (n=7), fields with known reserve status (n=17), explored prospects (green fields) but not proven by exploration drilling (n=23), and partially explored prospects (blind green fields, n = 10).

Most of the 57 prospects have been earmarked by the Indonesian Government for accelerated development in the Permen 15/2010 directive. This aims for an increase of c. 4,000 MWe in new installed capacity by the end of 2014 and would involve c. 40 prospects which are included in our classification. Fourteen fields with known reserve status were selected for evaluation and were ranked according to their electric power potential (Pe) and estimates of their levelized costs of electricity (LCoE). The suitability of these fields for the planned accelerated development of geothermal power can be assessed from the evaluation.

1. INTRODUCTION

Previous attempts to assess the electric power potential (Pe) of 15 developed geothermal fields in Indonesia and the Philippines have been evaluated by Hochstein and Crosetti (2011). The assessments were based on pre-development data and results could be compared with present day running field capacities (Crf) and earlier lapse-time Pe estimates which showed that present day Crf values are approaching earlier and revised Pe estimates over periods of 10 to 25 yrs of field exploitation. The initial Pe estimates were based on stored (useable) heat assessments using the stored heat-volume method and controlling data of flow-tested exploratory wells.

The 2011 study tested the significance of predicting the power potential Pe for 7 developed Indonesian fields by computing inferred levelized costs of electricity (LCoE) based on realistic Pe and pre-development data using Monte Carlo simulation. For 4 of the larger fields (Awibengkok, Darajat, Kamojang, and Wayang Windu) the predicted LCoE costs were found to be similar to their 2010 selling price of electricity; for two fields, which exploit volcanic geothermal reservoirs, it was lower. Considering that the LCoE costs were derived in part from Pe values based on pre-development data, the overall agreement between predicted LCoE costs prior to development and recent electricity selling costs shows that assessments of Pe and LCoE values at pre-development stage of a geothermal project can be used for realistic ranking of future developments.

A similar Pe and LCoE analysis is presented in this paper for some explored Indonesian prospects as they were known in 2010. Most of them are listed in several inventories, such as an earlier Pertamina inventory cited by Sudarman et al. (2000), an overview inventory by Hochstein and Sudarman (2008), and the Geological Agency Badan Geologi (2010) inventory, also quoted by Surya Darma et al. (2010). Exploration data of many of the 57 prospects are already available in the public domain but are also held and can be inspected at the Badan Geologi library (Bandung) and as bidding documents at the Ministry of Energy and Mineral Resources (Jakarta).

2. ADOPTED CLASSIFICATION OF SELECTED INDONESIAN GEOTHERMAL PROSPECTS

Between 2000 and 2010 preliminary estimates of the electric power potential Pe of most explored Indonesian prospects had already been circulated. The first list was compiled by PERTAMINA, cited by Sudarman et al. (2000), quoting a total potential (Σ Pe) of c. 19,650 MWe for 70 prospects. A recent inventory by the Badan Geologi (National Geological Agency of Indonesia) in 2010, and used by the Ministry of Energy and Mineral Resources (MEMR), lists a total power potential Σ Pe of c. 28,500 MWe for 265 prospects, most of them representing single thermal spring systems. A similar (Σ Pe) estimate of c. 27,000 MWe covering 256 prospects was quoted by Surya Darma et al. (2010). The estimates were used by the Ministry to formulate a policy to encourage an accelerated development of electric power production from selected fields listed in the inventories. The aim was to increase the total geothermal plant capacity from c. 1190 MWe in 2010 to c. 6,000 MWe by 2014 (documented in Permen 15/2010 of the Ministry).

When trying to rank the prospects considered for accelerated development, we found that classifications used in many inventories are not strictly applicable. The Badan Geologi classification (2010), defining geothermal reserves (probable and proven) and geothermal resources (possible, hypothetical, speculative), was found to be inadequate to classify the Indonesian prospects when considering the quality of available exploration and exploration drilling data. Other classifications, such as that by Williams et al. (2008) and an Australian code summarized by Williams et al. (2010), do not allow for the weight of single discovery wells and the type of geothermal system.

The term ‘proven reserve’ in these classifications implies that its exploitable volume is outlined in area and depth by a spatial array of productive exploratory wells. However, an analysis of historic developments of presently exploited Indonesian and Philippine geothermal fields has shown that outlining the volume of a productive reservoir was strictly not part of an exploration phase but became part of the development phase of the field. In practice, the status of a 'geothermal reserve' was therefore often assigned to prospects whose areal extent could approximately be predicted by surface surveys and whose average vertical extent could be inferred from a few exploratory wells. These did not outline a 'proven reserve' but were sufficient to assess its power potential (Hochstein and Crosetti, 2011). For this study, we prefer to use the term 'known (geothermal) reserve' to describe the sum of 'known' and 'probable' reserves.

Our grouping of prospects considering the available exploration data led to the classification of 4 classes of prospects:

Class A: includes all developed and producing Indonesian geothermal fields (7 prospects); fields which allow extension of present production have been called 'brown fields'.

Class B: includes fields with known reserve status and of known areal extent (from adequate resistivity and other surface surveys), the type of geothermal system and fluid and reservoir characteristics can be identified from completion tests of at least one flow tested (discovery) well. There are 17 prospects in this class which could support accelerated development. (15 are listed in Permen 15/2010).

Class C: includes prospects with adequate exploration data which define the type of geothermal system but without deep drilling information. These prospects are referred to as 'green fields', about 23 prospects belong to this class.

Class D: prospects with exploration data which do not allow recognition of the type of system or the likely areal extent of a reservoir nor the likely type of dominant reservoir fluid; they are classified here as 'blind green fields' (10 prospects).

In the Permen 15/2010 list, 'brown' field extension of 4 developed fields is expected to provide an additional plant capacity of c. 565 MWe. Inferred rapid development of 'known reserve' type prospects (equivalent to our class B type) was considered for 15 fields with a sub-total capacity of c. 1,625 MWe. Similar development of 14 class C 'green fields' would add another 1,150 MWe capacity, with development of 9 identified 'blind green' fields (class D) contributing an inferred 670 MWe capacity – all together, a total of c. 4,000 MWe for all 4 classes of prospects is indicated.

The distribution of the 57 geothermal prospects through Indonesia as they were known in 2010 is shown in Fig.1 (Sumatra), Fig.2 (Java and Bali), and Fig. 3 (for the Banda Arc Islands, Sulawesi, and the Moluccas). The prospects are identified by prospect Nr (taken from the Badan Geologi 2010 inventory), and by icons in insets which represent the four classes of prospects identified above. The figures are an upgraded version of similar maps used by Hochstein and Sudarman (2008).

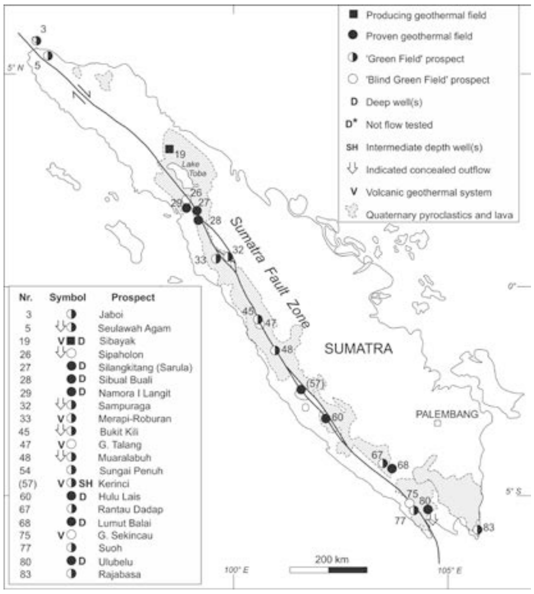

Fig.1: Location and classification by symbols of explored geothermal fields and prospects in Sumatra (end of 2010).

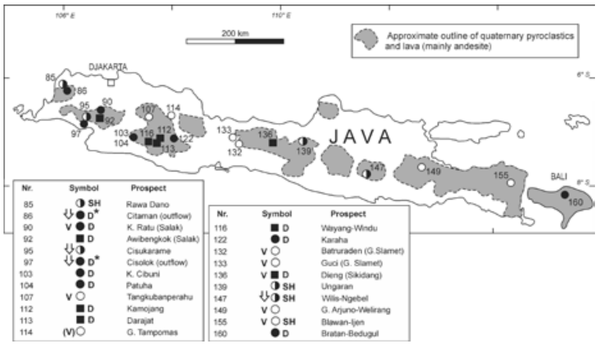

Fig.2: Location and classification by symbols of explored geothermal fields and prospects in Java and Bali. (Explanation of symbols is given in Fig.1 inset).

3. ASSESSMENT OF POWER POTENTIAL PE OF INDONESIAN PROSPECTS WITH KNOWN RESERVE STATUS

When plans for accelerated development of geothermal fields were proposed by the Ministry in 2010, 15 geothermal fields of known reserve were known whose development potential had been proven by flow- tested discovery wells. Two other fields (Nr 86 and Nr 90 in Fig.2) are not included here since area and volume of their productive reservoir are still uncertain. Two new fields have been explored in 2011 by deep drilling (Nr 188 and Nr 190 in Fig.3); however, the productivity of one prospect (Nr.190) still remains uncertain. The following Pe assessment of fields with known reserve status is therefore restricted to 14 prospects which are listed in Table 1.

The method used for computing the power potential of the 14 fields is the same as that referred to by Hochstein and Crosetti (2011) in their Appendix 1. It is also similar to the method listed in Sarmiento and Steingrimsson (2008). Construction of simple reservoir models allows for modelling of the type of geothermal system as defined, for example, by Hochstein and Sudarman (2008). Almost all 14 fields can be classified as ‘high’ temperature (Tav > 235 deg C) convective systems except for the Cisukarame prospect (Nr. 95 in Fig.2). Their reservoirs are hosted by young volcanic rocks. For a useable reservoir, usually between 1 and 2 km, sometimes to 2.5 km depth, the stored useable energy is mainly controlled by the inferred areal extent of the reservoir, as defined by its low resistivity capping structure and the extent and type of surface manifestations. Its average T can be assessed from well logs and fluid geothermometry prior to exploitation. Fluid abstraction over 30 yr and utilisation by flash plants has been adopted for the evaluation of the electric power potential of most fields; the exploitation of the Cisukarame (ouflow) reservoir requires the use of binary plants. Other parameters are similar to those used previously in the Hochstein and Crosetti (2011) study. The Pe values were computed using a Monte Carlo simulation to define the associated uncertainties in terms of integrated probability bounds (listed for p= 0.05, p= 0.5 (mean) and p =0.95 in Table 1). All estimates are conservative.

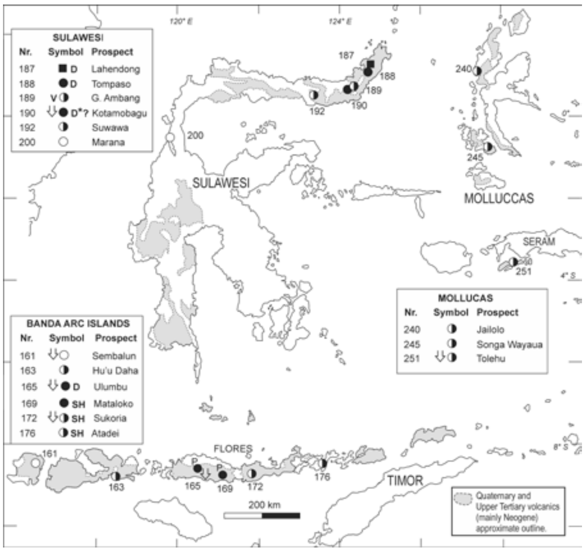

Fig.3: Location and classification by symbols of explored geothermal fields and prospects in the Banda Arc islands, Sulawesi, and the Molluccas. (Explanation of symbols is given in Figure 1 inset).

The data in Table 1 show that Pe values for 8 fields are within the range of 100 MWe and 300 MWe, the potential of 4 fields is between 30 MWe and 100 MWe , the Pe values of 2 fields point to developments with < 30 MWe capacity. The Pe values listed in Table 1 can be compared with estimates of a sub-total of c. 330 MWe predicted by Gunderson et al. (2000) for prospects Nr 27, 28, 29 in the Sarullah Block, a sum similar to that of 355 MWe for the same fields listed in Table 1. A note by PGE to the Ministry (MEMR) in July 2010 confirmed the order of magnitude of these estimates. For an overview, the Pe estimates are plotted in Fig. 4 versus independent Pe estimates from other sources. The figure indicates that although for certain fields the Pe value can differ significantly, the total of different surveys is similar. For the 6 fields in Sumatra, the Pe sum of our estimates (Table 1) is c. 1,000 MWe, the sum based on estimates from other sources (Fig.4) is about 1,100 MWe.

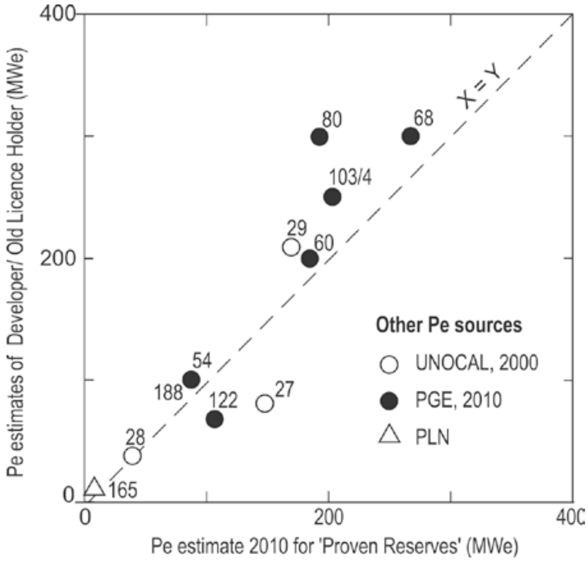

Fig. 4: Plot of Pe estimates of 12 Indonesian fields with proven reserve status versus independent Pe estimates of potential developers (end of 2010).

Table 1: Pe and LCoE Data for Geothermal Prospects (Known Reserve Type)

Nr	Prospect	A	ΔA	Pe	p (Pe) **	LCoE	p(LCoE) **
		[km²]		[MWe]		[US cents/kWh]	
27*	Silangkitang (Sil)	14	±2	150	90-215	7.9	6 -10.5
28	Sibual-Buali (SiB)	9	±2	35	20- 60	13.8	
29*	Namora Ilang (NiL)	15	±5	170	105-250	7.2	
60*	Hulu Lais (HuL)	25	±5	185	120-265	7.7	
68*	Lumut Balai (LeB)	30	±5	270	155-415	7.8	5.5 -10.5
80*	Ulubelu (Ulu)	15	±5	195	135-270	8.4	6.3 -11
97*	Cisukarame (Cisuk)	10	±2	40	25-60	11.1	
103*	Cibuni (Cib)	5	±1	80	60-105	8.1	
104*	Patuha (Pat)	8	±1.5	125	90-165	7.4	
122*	Karaha (Kar)	14	±2	105	65-155	9.9	
160	Bedugul (Bed)	25	±5	275	160-425	7.6	5.5-10.5
162	Mataloko (Mat)	4	±1	20	15-30	12.0	9-16
165	Ulumbu (Ulum)	>2		>4	?	25	
188*	Tompaso (Tom)	10	±2	85	55-155	8.4	6.4-11

Note: * Prospect also listed in the Permen 15/2010 list for accelerated development. ** Denotes the integrated probability at p=0.05 (1st value) and p= 0.95 (2nd value).

4. ASSESSMENT OF LEVELIZED COSTS OF ELECTRICITY (LCOE)

The LCoE costs were estimated using the same information and the same procedure as described previously by Hochstein and Crosetti (2011). The Pe value, reservoir type of the prospect, and the total development costs were treated as primary (internal project) information. Information related to power demand, grid connection, and line investments were used as modifying (external) inputs. Other information (site access, terrain, environmental protection and natural hazards) was incorporated by using appropriate weight (multiplier) functions.

LCoE costs were computed in terms of 2010 constant currency units such that the present value (PV) of revenues equals the life-cycle costs over investment/development period and a 30 yr operating period. The discount rate was based on weighted costs of capital (WACC) defined in terms of probability which reflect: the range of possible capital structure, risk premia, and risk-free interest rates. The Monte Carlo simulation was also used to obtain the probability distribution for present value (PV) of total project capital and operating costs. The 'mean' LCoE values obtained are listed in Table 1 and refer to a cumulative probability of $p = 0.5$. For a few prospects the integrated probability values for $p = 0.05$ and 0.95 are also listed.

The 'mean' power potential Pe has been plotted versus 'mean' LCoE costs in Fig.5. The data points fall within a broad band indicating an overall inverse exponential trend of LCoE costs as a function of project and Pe size, a trend which is already indicated in a similar presentation for the 7 developed Indonesian fields (Hochstein and Crosetti, 2011). The scatter of data points in Fig.5 is affected by the type of geothermal reservoir used as model. The 'vapour-dominated' reservoirs of Kamojang (Ka) and Darajat (Da), for example, allow a highly cost-effective (low LCoE) production of electricity; the same applies to the vapour-layer system of Patuha/Cibuni. However, the LCoE costs for the Wayang Windu field (WW), also a 'thick' vapour-layer system, are higher since, for a long-term capacity of 300 MWe, its proven deep 'brine–layer' has to be included which increases costs. The data in Fig.5 have also to be seen within the frame of government policy which caps at present the electricity selling price by producers at 9.7 [US cent/kWh].

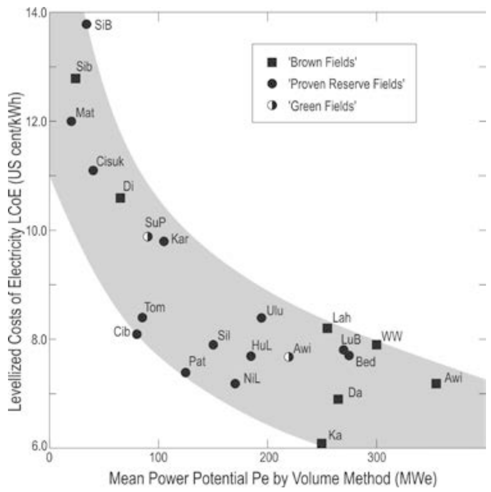

Fig.5: Plot of mean Pe estimates of Indonesian developed fields and those with known reserve status (this study) versus computed levelized costs of electricity; all values are based on pre-development data.

5. CONCLUSION

Present plans for an accelerated development of power production of Indonesian geothermal fields, involving an increase by c. 4,000 MWe at the end of 2014, are based on a Government directive (Permen 15/2010). Ranking of 57 explored geothermal prospects as they were known in 2010 has been attempted in our study to ascertain the potential of these prospects for accelerated development. The fields and prospects were ranked allowing for their exploration status which lead to a selection of 17 known reserve fields. This group of fields will be the first and main target for the proposed accelerated development. The Permen 15/2010 decree asks for an increase of a sub-total of c. 1625 MWe of capacity to be installed in fields with known reserve status. Fourteen of these fields were included in our analysis of their power potential (Pe) and their levelized costs of electricity (LCoE). The fields were independently selected according to their exploration status; ten of the fields are listed in the Permen 15/2010 document.

The sub-total of c. 1,465 MWe of potential plant capacity of 13 selected fields is similar to that inferred in the Permen 15/2010 directive (the large Bali prospect is excluded here since it is not cited in the Permen document). The levelized costs of electricity (LCoE) to be produced from 10 of the 14 analysed fields is below the Government capping prize of 9.7 US [cent/kWh] but above the 7 [cent/kWh] level; eight of the 14 fields have an electric power potential Pe greater than 100 MWe. Using the results of our study, a revision of the goals and the suggested time frame of accelerated development of Indonesian geothermal fields and prospects is indicated.

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