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GEOTHERMAL RESOURCE RISK IN INDONESIA – A STATISTICAL INQUIRY

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ABSTRACT

This paper presents a statistical study of the geothermal resource risk in Indonesia, specifically, that the resource base and well productivity are adequate and that the drilling cost per well is reasonable. This paper is timely because the Government of Indonesia is now embarking on an ambitious plan to develop up to 4,000 MW of geothermal power capacity by 2014-2015 and a longer-term target of 9,500 MW by 2025. This study relies on the resource base estimates made by the Indonesian Government-owned enterprise P.T. Pertamina (now "PGE") for nearly 100 sites, and productivity data on 215 wells in the country in the GeothermEx archives; these wells comprise some 80% of the production wells drilled in Indonesia. Pertamina's assessments are shown to be consistent; such a thorough national inventory of the geothermal resource base is available from very few countries. The resource base (proved-plus-probable-plus-possible) at a site ranges from 10 MW to 800 MW with a log-normal distribution. More than 70% of the known Indonesian fields have a resource base greater than 50 MW and nearly half of the fields (about 40) offer a resource base of 100 MW or more.

Commercial wells in Indonesia vary in capacity from 3 MW to more than 40 MW, with a median value of 9 MW. The mean, median and the maximum well productivity encountered in Indonesia are larger than seen in most countries; we believe the most likely range of well productivity worldwide is 4 to 6 MW. The commercial wells in Indonesia tend to fall in one of four groups in terms of capacity: (a) 3 to 5 MW representing "tight" wells; (b) 7 to 9 MW representing "typical" wells; (c) 15 to 19 MW representing wells that usually produce from a 100% steam-saturated but otherwise moderate-temperature reservoir or from a "steam cap"; and (d) greater than 27 MW representing "ultra-high" temperature and/or highly permeable reservoirs. The last two types of wells, which occur in relatively few countries other than Indonesia, represent 40% of the 215 wells studied in this paper.

Geothermal wells in Indonesia are mostly in the 1,000 to 2,800 m depth range and the drilling success rate ranges from 63% to 73%, which are also typical in most countries. Using an existing correlation of drilling cost versus well depth from several countries, and the defined statistics on well depth and productivity in Indonesia, we estimate that the cost per MW well capacity in Indonesia is statistically less than seen in many countries, the most probable value being in the range of \$300,000 to \$400,000 per MW. The average drilling success rate and well capacity in Indonesia show a clear "learning curve" effect; both success rate and well capacity tend to increase with the number of wells drilled, eventually reaching a plateau.

Given that (a) more fields with large resource bases are encountered in Indonesia than in most other countries, (b) well capacity in Indonesia typically is larger than in other countries, and (c) drilling cost per well in Indonesia is smaller than in most countries, the overall resource risk in geothermal projects in Indonesia should be lower than in other countries.

INTRODUCTION

Indonesia has perhaps the largest number of known geothermal fields and most ambitious plans for accelerated geothermal power development in the world: 4,000 MW by 2014-2015 and 9,500 MW by 2025. Figure 1 is a map of the country showing the most well known geothermal sites (red dots). However, there is a perception among some geothermal developers and financiers outside Indonesia that the resource related risk in geothermal development in Indonesia is substantial. Yet, we find no statistical basis for this perception, even though there are some 100 known geothermal fields and prospects in the country, and nearly 300 deep wells. In this section we analyze the resource risk elements in Indonesia in a quantitative way and compare them to the same resource risk elements in other countries with existing or imminent geothermal development.

Figure 1: Selected Indonesian geothermal areas.

There are at least four fundamental requirements that must be satisfied for any commercial geothermal development project; these are:

(a) adequate resource base;
(b) adequate well productivity;
(c) acceptable drilling cost per well; and
(d) benign fluid chemistry.

We will analyze here the uncertainty associated with the first three of the above requirements in Indonesia compared to that in other countries.

ADEQUACY OF RESOURCE BASE

Before acquiring a geothermal development concession in a country a developer needs to have a reasonable understanding of the resource base available at the site. In many countries this information is incomplete or unavailable, whereas in Indonesia the government developer PT Pertamina had in the past systematically explored most of the prospective areas, drilled deep wells in several fields and assessed the proved, probable and possible resource base in nearly all prospects. Figure 2 presents a histogram of the total resource base (proved + probable + possible) in Indonesian fields as estimated by Pertamina. The resource base displays a wide range, from 10 MW to nearly 800 MW.

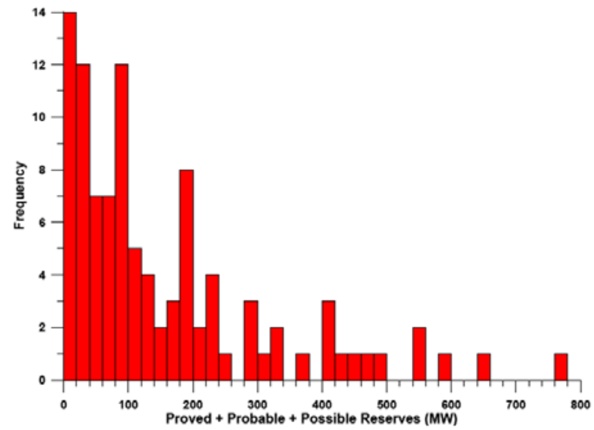

Figure 2: Histogram of total resource base in geothermal fields in Indonesia.

As expected in any nationwide assessment of this type, the histogram indicates the occurrence of progressively more fields with smaller reserves, that is, an approximately log-normal distribution of resource base. To verify this outcome, in Figure 3 we have plotted the logarithm of the total resource base as a function of the frequency of occurrence on a normal probability scale. A clear linear trend of data points on this plot establishes that the distribution of the resource base is log-normal. Therefore, Pertamina's assessment of resource base values appears consistent, and thus the prospect inventory developed by Pertamina has significant value for developers looking for project sites in the country. Such a consistent national inventory of resource base is available from relatively few countries trying to attract geothermal developers.

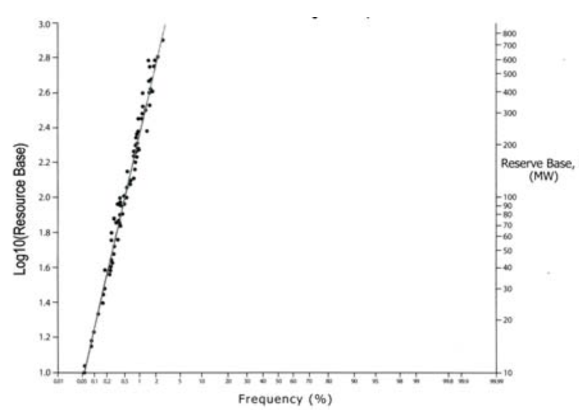

Figure 3: Frequency distribution of total geothermal resource base in Indonesia fields on a log-normal probability plot.

Figure 4 is a plot of the cumulative frequency of resource base as a function of the MW capacity in Indonesian fields. This figure indicates that there is 50% cumulative probability that a geothermal field will have a resource base exceeding 100 MW; which is an attractively large scale for commercial development. It is unlikely that a foreign developer would be interested in developing a field in Indonesia unless it offered the prospect for developing at least 50 MW; Figure 4 shows that more than 70% of the Indonesian fields (more than 50 fields) exceed this threshold. The occurrence of so many potentially available commercial project sites in a country is rare. The total estimated resource base in Indonesia in about 100 known fields amounts to about 16,000 MW. It is likely that further exploration and drilling will reveal even more exploitable geothermal sites and increase the inventory of the resource base known today. Therefore, there is a sufficient resource base in the country to justify the development target of the Government of Indonesia.

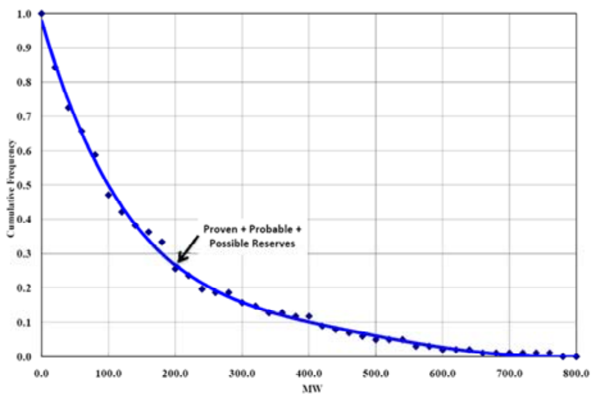

Figure 4: Cumulative frequency of proven + probable + possible resource base in Indonesia.

ADEQUACY OF WELL CAPACITY

We have accumulated statistics on 215 deep geothermal wells in Indonesia, which represent a large majority of all geothermal wells in the country; most of the individual well data remain confidential to the developer. This is an adequate database for analyzing the well capacity risk; to our knowledge no such database has been reported previously. Figure 5 presents a histogram of per-well MW capacity in Indonesia based on the data from the 215 wells. A well capacity of less than 2 MW, and in some cases 3 MW, is considered non-commercial well and the well is usually turned into an injection well or observation well, or is abandoned. Figure 5 indicates that about 38% of wells are less than 2 MW in capacity, and as such, non-commercial. Therefore, the drilling success rate in Indonesia to date is about 62%. However, this database includes exploration wells, confirmation wells, development wells and make-up wells; the drilling success rate generally becomes higher as a project moves from exploration through the confirmation, development and operational stages in succession. The average well success rate in the development and operational stages of the oldest operating field in Indonesia (Kamojang) has been about 73%. This level of development drilling success is typical in most countries with geothermal potential.

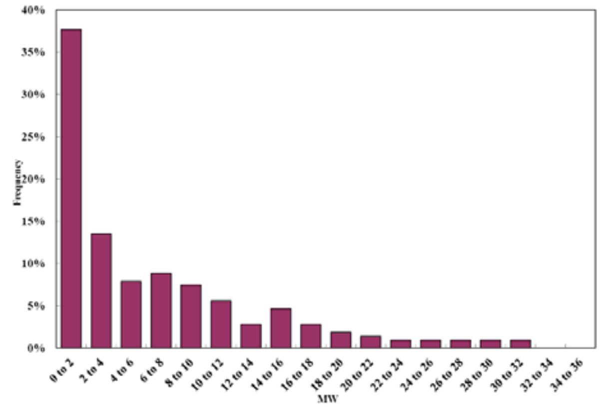

Figure 5: Histogram of well capacity, Indonesian fields (including non-commercial wells).

Figure 6 presents a histogram of MW capacity of all commercially successful wells, which are defined here as wells with a capacity of at least 3 MW. Figure 6 indicates an approximately log-normal distribution with a clear peak (at 3 to 5 MW).

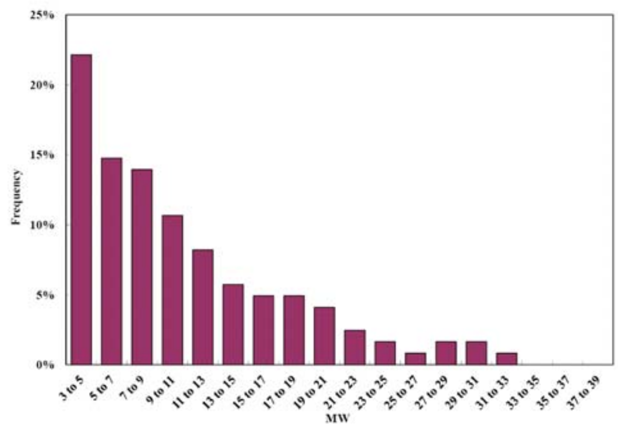

Figure 6: Histogram of well capacity, Indonesian fields (commercial wells only).

Figure 7 shows a plot of the cumulative frequency of well capacity of the commercial wells in Indonesia; the wells vary in capacity from 3 MW to more than 40 MW, with a median value of 9 MW. The mean, median and maximum value of well capacity in Figure 7 are all higher than seen in other countries. Worldwide, a geothermal well capacity of 4 to 6 MW is most common. It is worthwhile investigating the reason for this difference between the well capacity distribution in Indonesia and most other countries.

Geothermal wells have been drilled in Indonesia continuously since the 1970s. Given that over the last few decades the state-of-the-art and experience in geothermal well drilling and field development have improved worldwide, let us consider the statistics of wells drilled in Indonesia only since 1990, when the pace of drilling activity accelerated in Indonesia. A histogram of the MW capacity of all wells in

Indonesia since 1990 that are at least 3 MW in capacity is shown in Figure 8.

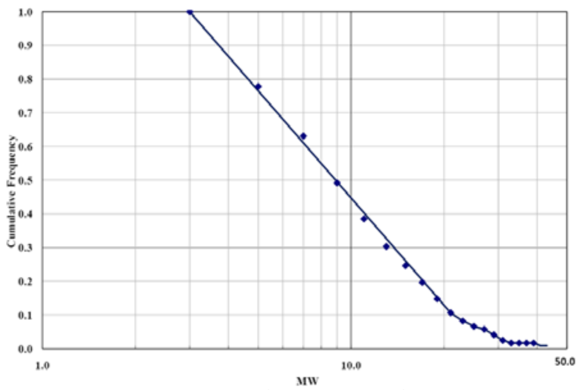

Figure 7: Cumulative frequency of well capacity, Indonesian fields (commercial wells only).

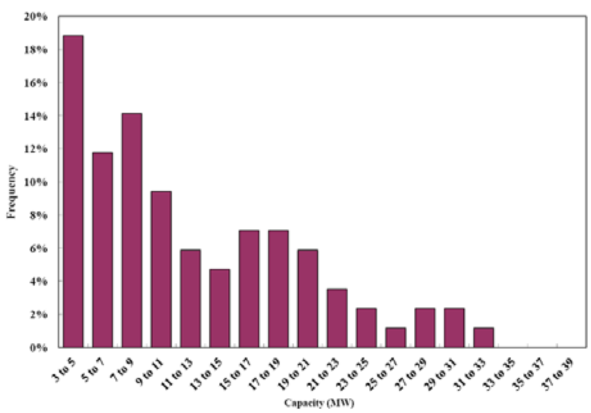

Figure 8: Histogram of commercial well capacity, Indonesian fields, (post 1990).

This figure reveals that when the pre-1990 wells are ignored, the histogram of well productivity is no longer log-normal but has multiple modes: Mode 1 (3 to 5 MW), Mode 2 (7 to 9 MW), Mode 3 (15 to 19 MW) and Mode 4 (27 to 31 MW).

This multi-modal distribution can be explained by referring to the several classes of geothermal fields discovered over the last two decades in Indonesia. Mode 1 typically represents "tight," marginal wells that can randomly occur in any geothermal system, and as such, are not unique to Indonesia. Mode 2 (7 to 9 MW) wells are often referred to as the "most likely" in Indonesia. For example, JICA and WestJEC (2007) and JICA and WestJEC (2009) refer to 8 MW as the typical capacity for wells in Indonesia. Mode 2 wells represent those producing from typical high-temperature liquid-dominated wells, as found in many countries. However, given that the Mode 3 and Mode 4 wells have much higher commercial value, the assumption of an 8 MW well capacity for the analysis of the resource risk in Indonesia overestimates this risk. Let us examine what underlying resource conditions the Modes 3 and 4 wells may represent.

Figure 9 is a plot of the MW capacity versus temperature of all 215 wells. This figure indicates two clusters of wells, one in the 230°C to 250°C range and the other in the 300°C to 340°C range. It can be shown that most of the Mode 3 wells falling in the 230°C to 250°C range typically represent wells producing from a 100% saturated steam reservoir, and the Mode 4 wells falling in the 300°C to 340°C range represent ultra-high temperature liquid-dominated wells, sometimes producing from a "steam cap". Mode 3 and Mode 4 wells occur in relatively few countries besides Indonesia.

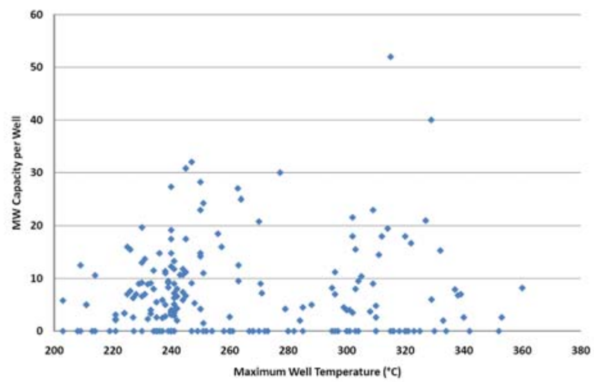

Figure 9: Maximum well temperatures vs. MW capacity, Indonesian fields.

This diversity in the MW characteristics of wells in Indonesia makes the assessment of the resource risk more challenging. For example, Figure 10 is a histogram of the temperatures of the 215 wells; this figure shows only two modes rather than four as seen in Figure 8, but similar to what is seen in Figure 9. Figures 8 and 9 imply that Modes 3 and 4 are uniquely defined and represent well capacities more attractive than are found in all but a few countries, whereas Mode 2 represents wells with a broad range of temperatures and productivity found in many countries, and Mode 1 represents generally tight and/or relatively low temperature wells. Given that the Mode 3 and Mode 4 wells together represent nearly 40% of the 215 wells, we conclude that on a nationwide basis, Indonesia represents an unusually high occurrence of commercially attractive wells.

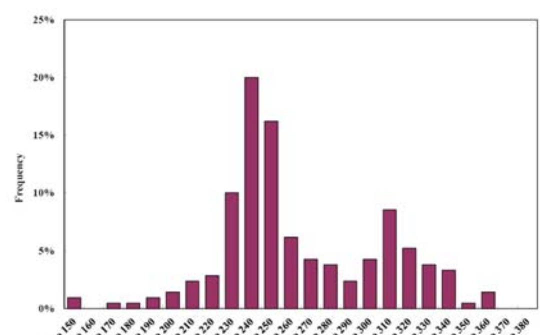

Figure 10: Histogram of maximum well temperature, Indonesian fields.

WELL DEPTH AND COST

Depth is the main determinant of the drilling cost of a geothermal well. Typically drilling cost in any country increases exponentially with depth; see, for example, GeothermEx (2004). Therefore, the depth distribution of wells in Indonesia is an important issue in the assessment of resource risk in the country. Figure 11 shows a histogram of the depths of the 215 wells indicating that geothermal well depth in Indonesia ranges from about 1,000 to 2,800 m, which is also representative of the range found in most countries with geothermal fields (GeothermEx, 2004).

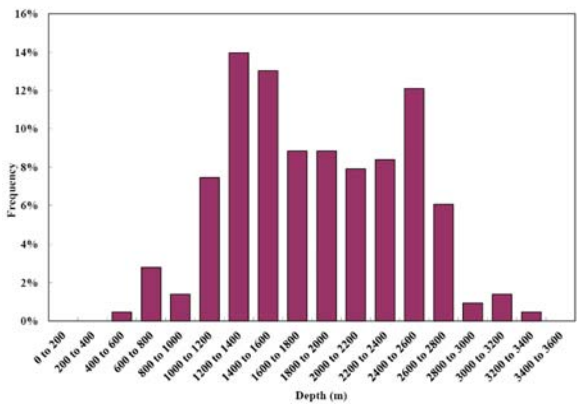

Figure 11: Histogram of well depth, Indonesian fields.

Although there are no detailed statistics, we know from experience that drilling cost in Indonesia is somewhat lower than seen in most countries. We have already shown that drilling success rate in Indonesia is comparable to that in other countries. Given that (a) the well depth and drilling success rate in Indonesia are comparable to those in other countries, (b) the drilling cost per meter is somewhat lower in Indonesia than seen in other countries, and (c) that well capacity is generally higher in Indonesia than in other countries, we conclude that the cost per MW of well capacity in Indonesia is statistically lower than encountered elsewhere.

Figure 12 presents a plot of the MW capacity versus depth of the 215 wells. It shows two clusters. The points clustered around a depth of 1,500 m represent mostly Mode 3 wells while the points clustered around 2,500 m depth represent Mode 4 wells. Figure 13 is a histogram of the drilling cost per MW of successful wells in Indonesia, based on the correlation in GeothermEx (2004) and the MW capacity versus depth data in Figure 12. This figure shows that the drilling cost per MW well capacity in Indonesia ranges from US$100,000 to nearly $2,000,000 the most probable range being $300,000 to $400,000 per MW; this is significantly lower than in most other countries.

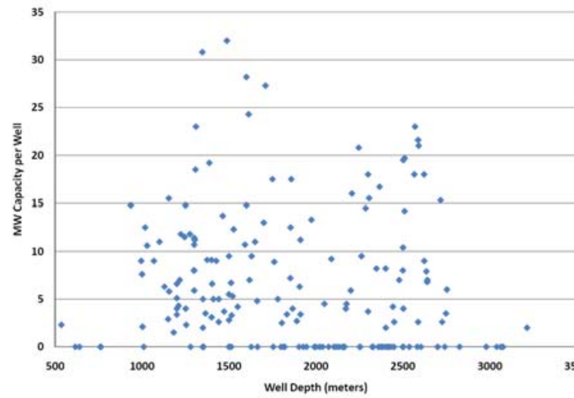

Figure 12: Well depth vs. MW capacity, Indonesian fields.

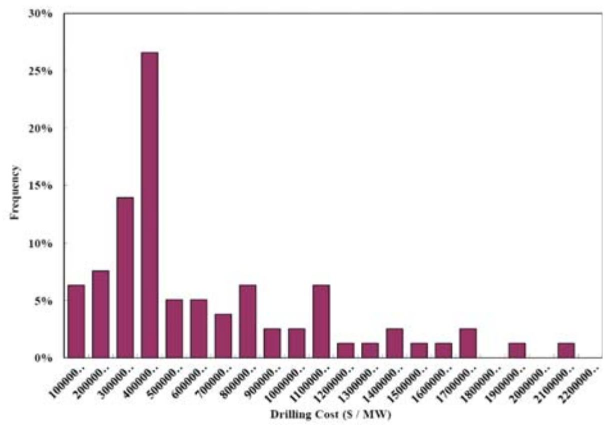

Figure 13: Histogram of drilling cost per MW for successful wells, Indonesian fields.

THE LEARNING CURVE EFFECT ON RESOURCE RISK

Geothermal resource development has been going on in Indonesia for more than three decades. Over this long period the risk should have lessened due to improvements in technology and/or experience gained in avoiding or mitigating such risk. Therefore, we examine to what extent the learning curve effect may have positively influenced some elements of resource risk in Indonesia. Figure 14 is a plot of the average drilling success versus the number of wells drilled (not including some 20% of the wells on which we have no data) in Indonesia.

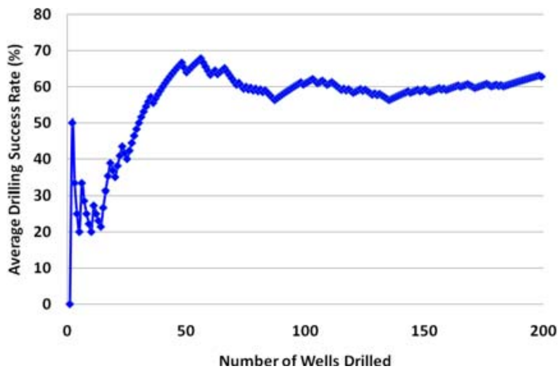

Figure 14: Average drilling success rate vs. number of wells drilled in Indonesia.

Clearly, the success rate in drilling has fluctuated but steadily increased in the overall trend as more wells have been drilled, until a stable average success rate of about 62% was reached (after about 90 wells), when the learning curve effect reached a plateau. As mentioned before, the database in Figure 14 includes wells in all stages of geothermal projects. Since the average drilling success rate progressively increases through the exploration, confirmation, development and operational stages of a project, a drilling success rate of 62% is an underestimate for the development and operational stages, when the majority of the wells are drilled in a project.

Figure 15 is a plot of the average production capacity of all wells drilled and the average production capacity of only the successful wells drilled in Indonesia as a function of the total number of wells drilled. Figure 15 shows that the average capacity of the successful wells reached a plateau of 9.8 MW after about 200 wells were drilled. Figure 14 shows that the drilling success rate plateaued at 62% after 200 wells were drilled. Therefore, the average capacity of all wells drilled should have stabilized at 9.8 x 0.62, that is, 6.1 MW after 200 wells; this is confirmed by the lower curve in Figure 15, implying that the statistics on the learning curve effect are internally consistent.

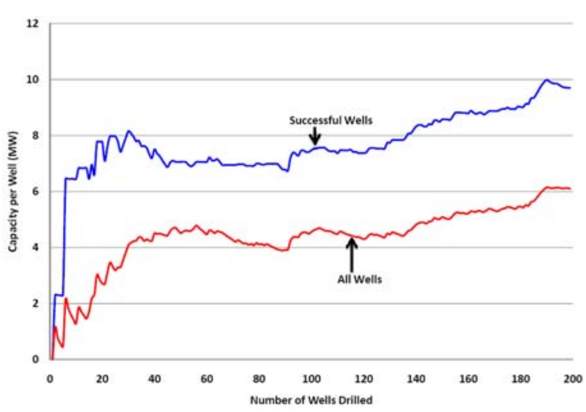

Figure 15: Average MW per well vs. number of wells drilled in Indonesia.

Figure 15 shows that, the capacity per well increased until it reached a plateau after about 40 wells were drilled. Then, after about 140 wells were drilled, a steady increase in the average well capacity ensued again, even though the well success rate remained nearly constant at about 62% (Figure 14) as further wells were drilled. This apparent discrepancy stems from the fact that over the last decade more and more wells of Mode 2 and Mode 3 have been drilled. Figure 15 shows a peak in the average capacity of successful wells of 9.8 MW, whereas the average capacity of all wells reached 6.1 MW, again reflecting an unchanged drilling success rate of 62%. Therefore, although the learning curve effect on drilling success rate plateaued at 62%, the average MW capacity per well kept on increasing because developers began tapping more Mode 3 and Mode 4 wells. In other words, the assumption that a typical well in Indonesia is slightly better than the 4 to 6 MW seen in other countries is unwarranted; it is substantially better (the average nationwide being about 10 MW) and is likely to climb even higher as new projects begin drilling more Mode 3 and Mode 4 wells.

The learning curve effect on the geothermal resource risk is best illustrated by considering a specific geothermal field rather than Indonesia as a whole. The Kamojang field in Indonesia is the best example for this illustration because it has the longest exploration, development and production history in Indonesia (since the 1970s); see Sanyal et al (2000) and Suryadarma et al (2010). Figure 16 shows the average drilling success rate (successful wells being greater than 2 MW in capacity) at the Kamojang field as a function of the number of wells drilled. Again, the drilling success rate increases with drilling until a plateau at a drilling success rate of 73% is reached after about 40 wells.

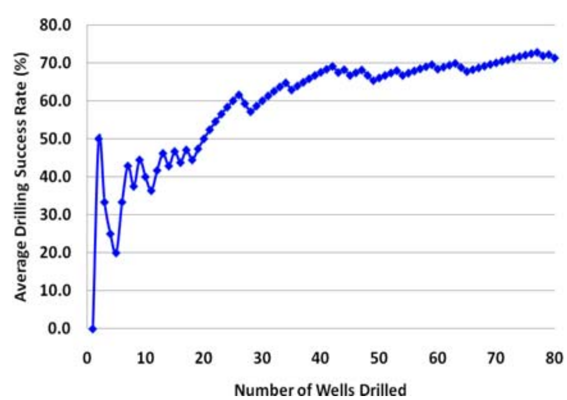

Figure 16: Average drilling success rate vs. number of wells drilled in the Kamojang field, Indonesia.

CONCLUSIONS

- Pertamina's assessments are consistent; such a thorough national inventory of the geothermal resource base is available from very few countries. The resource base (proved-plus-probable-plus-possible) at a site ranges from 10 MW to 800 MW with a log-normal distribution. More than 70% of the known Indonesian fields have a resource base greater than 50 MW, and nearly half of the fields (about 40) offer a resource base of 100 MW or more.

- Commercial wells in Indonesia vary in capacity from 3 MW to more than 40 MW, with a median value of 9 MW. The mean, median and the maximum well productivity encountered in Indonesia are larger than seen in most countries while we believe the most likely range of well productivity worldwide is 4 to 6 MW.

- The commercial wells in Indonesia tend to fall in one of four groups in terms of capacity: (a) 3 to 5 MW representing "tight" wells; (b) 7 to 9 MW representing "typical" wells; (c) 15 to 19 MW representing wells that usually produce from a 100% steam-saturated but otherwise moderate-temperature reservoir or from a "steam cap"; and (d) greater than 27 MW representing "ultra-high" temperature and/or highly permeable reservoirs. The last two types of wells, which occur in relatively few countries other than Indonesia, represent 40% of the 215 wells studied in this paper.

- Geothermal wells in Indonesia are usually 1,000 to 2,800 m in depth and the drilling success rate appears to range from 63% to 73%, which are typical also in most countries. Using a correlation of drilling cost versus well depth from several countries, and the statistics on well depth and productivity in Indonesia, we estimate that the cost per MW well capacity in Indonesia is statistically less than seen in most countries, the most probable value being in the range of $300,000 to $400,000 per MW.

- The average drilling success rate and well capacity in Indonesia show a clear "learning curve" effect; both success rate and well capacity tend to increase with the number of wells drilled, eventually reaching a plateau.

- This analysis also implies that there is a sufficient geothermal resource base in Indonesia and that it is possible to scale-up as proposed in the Government of Indonesia's development targets. However, it will be essential to have an adequate policy framework that will be seen as credible by developers and enhance the investment climate, especially if the private sector is expected to play a major role in the proposed expansion.

ACKNOWLEDGEMENTS

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