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Geologic Risks Assessment and Quantification in Geothermal Exploration Case Studies in Green Field and Developed Prospects

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ABSTRACT

Geological risk is the most difficult to assess and quantify among many exploration risks. This is because it consists of many risk factors with various level of uncertainty. Assessment of this risk needs geological understanding of the project area. In geothermal exploration this include the targeted geothermal system type, and the distribution and magnitude of thermal energy indicators defined by previous exploration (geology, geochemistry, and geophysics). Nevertheless, these key factors of assessment often unreliable, unrepeatable, and nonstandard, making the risk become difficult to identify or quantify. Therefore it is necessary to develop a standard assessment for quantifying geologic risk.

The purpose of this paper is to give an example on how geologic risk can possibly be quantified from various exploration data during early exploration up to well defined prospect. Therefore the study area is chosen in Galunggung area as an example for green field prospect and Patuha area as developed field but has not been produced yet.

The idea of assessment and quantifying risk is adopted from the developed method in petroleum evaluation project. Geologic risk is assessed by considering the probability that the three independent components of a large potential geothermal systems, in particular hydrothermal system, exist. They are heat source, reservoir rock and fluid (and to a lesser extent cap rock), and recharge-discharge area with its surface manifestation. The probability of geologic success (low risk) is obtained by multiplying the probabilities of occurrence of each of the above three components. The probability of occurrence each component is the result of assessment of the elements of the risk factors, which are expressed as unfavorable, questionable, neutral, encouraging, and favorable. The element of risk factor is all critical aspects of geologic risk that must be considered for the assessment, for example the element of risk of reservoir consists of temperature, fluid chemistry, area thickness, etc. The final result of assessment is probability of geological success that determined by value from 0.01 to 0.99, which can be translated by very high risk to very low risk respectively. The value of probability from Galunggung and Patuha will show how much risk that the operator facing. The challenge of this work is how to determine the element of risk and giving the value of probability occurrence to each element so that the method can be standardized, reliable and repeatable.

1. INTRODUCTION

Quantification of exploration risk helps to secure investments and contributes significant value to the financial valuation of assets. Exploration risk constitutes of various risks but in general could be classified as geologic risk such as drilling success, and non geologic risk such as fiscal risk, engineering risk, political risk etc. Among many exploration risks, geological risk is the most difficult to be assessed and quantified, because it consists of many risk factors with various level of uncertainty.

The concept of geological risk assessment and quantification in oil exploration has been discussed thoroughly for many years and currently has been well developed (Otis & Schneidermann, 1997). In geothermal exploration this has not been an established issue. Instead, similar assessment and quantification process of hydrocarbon is adapted to Engineered Geothermal System (EGS) in Cooper Basin, Australia (Cooper and Beardsmore, 2008). Here the geothermal resource is in a conductive system where the geological risk is defined as the product of four key geological factors; temperature (heat flow risk), thermal resistance risk, reservoir risk, and water risk.

On the contrary, if the geothermal project is in convective associated to volcanic system such as in Indonesia, the four components of the geologic factors above are differ. Here the targeted geothermal system mostly is hydrothermal system, where the component consists of (1) heat source (may be magma or cooling pluton or dyke), (2) reservoir with thermal fluids and to some extent the cap rock, where often has discrete geometry, (3) a surrounding ‘‘recharge region,’’ and (4) a (heat) discharge area at the surface with ‘manifestations’ (Hochstein and Browne, 2000). The availability and the conservation of these components during the geothermal energy production determine the sustainability of the exploitation and thus the economics of the project. Therefore, these four components are defined as geologic factor risks in convective (can be associated with volcanic) hydrothermal systems.

Thus, assessment of geologic risks for geothermal exploration needs geological understanding of the project area, the targeted geothermal system type, and the distribution and magnitude of thermal energy indicators defined by previous exploration (geology, geochemistry, and geophysics). Nevertheless, these key factors of assessment often unreliable, unrepeatable, and nonstandard, making the risk become difficult to identify or quantify. Therefore it is necessary to develop a standard assessment for quantifying geologic risk, hence the purpose of this paper.

2. RISK ASSESSMENT AND QUANTIFICATION

The idea of the assessment and quantifying the risk is adopted from the developed method in petroleum evaluation project by Otis and Schneidermann (1997). The concept is adopted here, in this study.

In order to assess the geologic risk, the definition of geologic risk must be determined. Cooper and Beardsmore (2008) consider the exploration of conductive geothermal system as follow: "Geothermal exploration is actually about finding a source of thermal power. Thermal power is related to both the temperature and the deliverability of the geothermal resource". Hence, the important keyword for exploration success, is thermal power and deliverability of the geothermal resource, which means although the thermal power was found, but if the deliverability or producible were unaccepted due to low resource, high acidity of fluid, high gas content etc., it can mean the unsuccessfulness of an exploration program. In contrast, the deliverability or producible geothermal resource is vary from area to area, depend on geothermal company strategy, engineering, political issue etc. In Indonesia particularly, most geothermal operators are looking for high enthalpy resource which capable of generating electricity in big scale, says greater than 50 MWe. In this case, the so called 'large resource' are controlled by suitable heat source, such as young magma body, large reservoir potential that is influenced by rock and fluid properties, recharge and discharge area for long term sustainability. These controls become the component for risk assessment to find the desired geothermal resource, i.e., the large potential geothermal system.

Assessment of the geologic risk, adopted from Otis & Schneidermann (1997) was conducted by considering the probability that this three independent components of a large resource geothermal systems, in particular hydrothermal system, exist. They are as described above are:

1. The presence of heat source (Pheat source)
2. The presence of reservoir rock and fluid (and to a lesser extent cap rock) (Preservoir), and
3. The well defined recharge and discharge area with its surface manifestation, which is also knowledge about upflow and outflow zone. (Pdischarge recharge)

The probability of geologic success (Pg) is obtained by multiplying the probabilities of occurrence of each of the three factors of the (large resource) geothermal system:

(Pg) = (Pheat source) x (Preservoir) x (Pdischarge recharge)

The probabilities that any of the geothermal system factors occur are estimated by first analyzing the available information. The risk assessment checklist shown in Tabel 1 was proposed to assist the geoscientist in examining as much information as possible.

Tabel 1: The risk assessment checklist lists the critical aspects of geologic risk assessment to help ensure all aspects have been considered. (modified from Otis and Schneidermann, 1997)

1) Heat Source	
Thermal potential of heat source (preferably magmatic or volcanic)	Presence of cap rock or seal
Geometry	Possible steam quality
Age	NCG content
Proximity to reservoir	Scaling potential
	pH and corrosion potential
	Flow rate and enthalphy
2) Reservoir	
Rock properties for thermal potential	**3. Recharge - Discharge**
Area	Heat loss
Thickness	Area extent
Temperature	Upflow – Outflow zone
Porosity - Permeability	Hidrology
Density	
Thermal conductivity / Heat capacity	
Fluid properties for thermal potential	
Fluid phase and Temperature	
Volume (Saturation of porosity or permeability)	
Density	

The assessments of the elements of the risk factors is recorded in a risk assessment worksheet as shown in Tabel 2. It is expressed as unfavorable, questionable, neutral, encouraging, and favorable. If the data is little or no data, the assessment is based only on evaluating the analogs and the chance that the model will reflect the analog. And if data are acquired, the opinions which is supported by the data is begin to be developed. These opinions may be positive (encouraging or favorable) or negative (questionable or unfavorable). If the factors have equal probability of positive or negative outcomes are given a probability of occurrence of 0.5.

According to Otis & Schneidermann (1997), the assessments of encouraging or questionable are based on indirect data that support or do not support the model. In this study, examples of indirect data for an assessment of encouraging include proximity of the system to volcanic center, occurrence of hot springs etc. In addition, the examples of indirect data for an assessment of questionable include lack of active surface manifestation; system is located slightly far from volcanic center, etc.

The use of indirect makes the assessment more dependent on the model than on the data, and the opinions are supported, but not confirmed, with data. If the indirect data supporting the model, probability of occurrence is encouraging, and the values is between 0.5 and 0.7. If indirect data do not support the model, probability of occurrence is questionable, and the values is between 0.3 and 0.5.

On the other hand, assessments of favorable or unfavorable are based on direct data that tend to confirm or disprove the model. Examples of direct data for an assessment of favorable include thermal gradient from slim hole, the result of well testing which is promising, the location of well that in line with other production well and within the defined system boundary, etc. Examples of direct data for an assessment of unfavorable include results from well testing that show high temperature but no flow, well with low temperature, acid fluid from deep reservoir, etc. If direct data supports the model, probability of occurrence is favorable, and the values between 0.7 and 0.99. If direct data do not support the model, probability of occurrence is unfavorable, and the values between 0.01 and 0.3.

All the assessments is recorded in the worksheet, a value corresponding to the scale which is shown at the bottom of the worksheet (in Tabel 2) is assigned. The total risk computation is shown in the upper part of Tabel 2.

The result will range from very low risk to very high risk. The Very low risk (Pg between 0.5 and 0.99, or better than 1:2) suggest that all risk factors are favorable. This result may be associated with wells that have been tested and show proven result suitable with company strategy. The Low risk (Pg between 0.25 and 0.5, or between 1:4 and 1:2) suggest that all risk factors are encouraging to favorable. This result may be associated with wells that have been tested and show proven result but slightly low entalphy and still below company expectation. The Moderate risk (Pg between 0.125 and 0.25, between 1:8 and 1:4) suggest that two or three risk factors are encouraging to favorable, with one or two factors are encouraging or neutral.

In this paper we present geological risk assessment of two geothermal fields: Patuha Field, representing a discovery field, well developed field but has not produced electricity, and Galunggung Field, where exploration has just started on mid 2013 and until this paper is written, the MT program is still on progress. The idea is to compare exploration stage and data which may suggest the risk caused by lack of direct data, the role of indirect data or analogue model from those two extremes of geothermal fields

3. CASE STUDY IN PATUHA FIELD – THE NON-PRODUCTIVE WELL DEVELOPED FIELD

Patuha Geothermal Field in West Java Province, Indonesia, has completed exploration activities but the field has not yet produced electricity. Geological, Geochemical and Geophysical survey were able to delineate the area extent of the field which later on confirmed by 17 Temperature Core Holes (TCH) and more than 14 proposed production wells (PPL).

The early exploration activities covered larger area including Patuha Crater; the main geothermal prospects are, Kawah Putih Crater, five hundred meters south of Patuha Crater, Cibuni Crater, about 2.5 km west of Patuha Crater, and Urug Mountain-Ciwidey Crater, about 5 km to the south west. In this paper we discuss only Patuha and Kawah Putih Crater area.

3.1. Assessment of Heat Source Probability Occurrence

The Patuha-Kawah Putih Crater form a volcanic complex with estimated cone volume about 60 km2 (Faturrahman et.al., 2013). The radiometric dating of some volcanic rock have the age value range between 120,000 – 1,250,000 years ago (Fauzi et al., 1994). These values are within a range of potential geothermal resource hosted in volcanic rock, that is between 50 000 – 250 000 years ago (Wohletz, 1992). The geochemistry study suggests the association of potential heat source with Patuha-Kawah Putih active volcano (Idrus Alhamid, 1989; Sriwana et al., 2000). This volcanic heat source is confirmed by resistivity model from Schlumberger DC-resistivity (Idrus Alhamid, 1989) and MT survey (Layman and Soemarinda, 2003). The volume of volcanic cone (geometry) and its corresponding age suggest a favorable probability factor which is well documented by data.

The predicted reservoir is delineated by 10 ohm-m contour from DC-resistivity survey (Idrus Alhamid, 1989), and later on confirmed by MT survey (Layman and Soemarinda, 2003). This reservoir is suspected beneath Patuha-Kawah Putih Crater. It is then proved by drilling of of TCH16, TCH17 and PPL08 (WJEC, 2007; Schotanus, 2013). The proximity of the predicted reservoir and the potential heat source suggests a strong correlation that gives the probability factor a favorable value, and is significantly documented by data.

3.2. Assessment of Reservoir Probability Occurrence

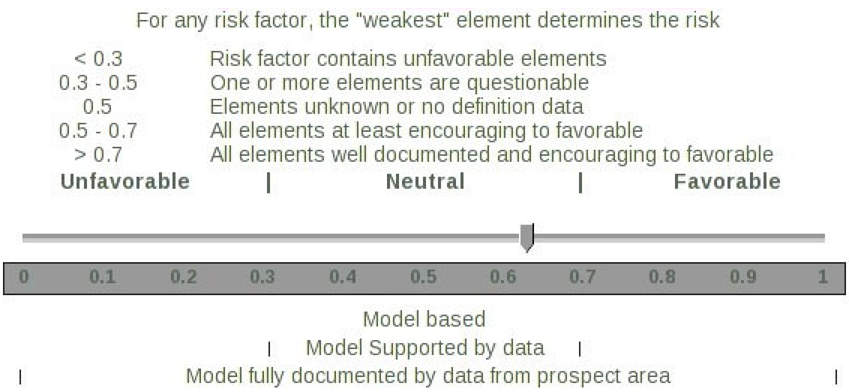
Assessment of Reservoir probability consists of two factor; rock properties and fluid properties. The rock properties for risk factor area, thickness, and cap rock are well defined by TCH and PPL wells. They are also significantly identified by DC-resistivity (Idrus Alhamid, 1989) and MT data (Layman and Soemarinda, 2003). It can be said that all the three sub-factors above give probability favorable value.

On the other hand, the probability factor porosity-permeability, density and thermal conductivity are based on common assumption or in other word from model supported by data. The characteristic of these latter three factors are assessed using analogy with physical properties and geologic similarities with other field in the world. In addition, reservoir simulation study give a compromise result for porosity-permeability, density and thermal conductivity. Therefore all of these three factors are given the probability value neutral to encouraging, because the characteristic of these elements are taken from model, supported by analogy and to lesser extent by data.

Tabel 2: The risk assessment worksheet provides a method for transferring qualitative judgments on geologic risk to quantitative probability of geologic success. (modified from Otis and Schneidermann, 1997)

Risk Assessment Computation						
Probability of large geothermal resource discovery		(1) Probability of Heat Source		(2) Probability of reservoir		(3) Probability of recharge-discharge
---------------------	=	---------------------	x	---------------------	x	-----------------------
Geologic risk factor =		1 / geothermal resource discovery		=		-----------------------

Probability factor	Unfavorable	Questionable	Neutral	Encouraging	Favorable
1. Heat Source					
1.1. Geometry					
1.2. Age					
1.3. Proximity to reservoir					
etc					
	Unfavorable	Questionable	Neutral	Encouraging	Favorable
2 Reservoir					
2.1.Rock properties					
2.2. Fluid properties					
2.3. Steam quality					
etc					
	Unfavorable	Questionable	Neutral	Encouraging	Favorable
3. Recharge - Discharge					
3.1. heat loss					
3.2. area extent					
3.3. upflow - outflow					
etc					



The reservoir fluid properties such as temperature and fluid phase are well documented by well data. The reservoir temperature is in agreement with geothermometer calculated from sample taken from manifestation and the occurrence of alteration mineralogy from borehole data and surface mapping (WESJEC, 2007). Fluid phase has been proved as steam in production well from well testing. However, fluid density and saturation is assigned value from other field. Thus, the reservoir temperature and fluid phase are having probability value of favorable, but fluid density and saturation are neutral to encouraging.

The steam quality or purity in Patuha is suspected to have high NCG and low pH that can cause engineering problem. The scaling may or may not be a problem. However, this conclusion is mainly supported by surface geochemistry data from manifestation, since down hole samplings were not carried out. Therefore the probability occurrence for these three factor are assigned as questionable to encouraging. On the other hand, the fluid enthalpy and flow rate are well documented from well testing data. Hence, the probability occurrence of steam quality factor is assigned as favorable.

The reservoir assignment gives risk value between neutral (porosity-permeability, thermal conductivity, rock density and scaling potential) to favorable (area, thickness, temperature etc.). Because the weakest element determines the total risks in any risk factor, the reservoir risk factor is assigned as neutral.

3.3. Assessment of Recharge - Discharge Probability Occurrence

This assessment consist of three elements:

1. occurrence and intensity of natural heat loss discharged by manifestation, hereafter called heat loss element
2. the prominence of evidence of upflow and outflow, also called upflow-outflow element
3. the recharge-discharge area extent.

All the elements have been well documented with prominent fact and detailed data, therefore all elements have favorable probability occurrence, with value 0.9. The details of the documented data and fact are discussed below.

The natural heat loss calculated from surface manifestations that consist of crater lake, fumaroles, hot and warm springs and pools is approximately >30MWth (Faturrahman, et.al., 2013). This field potential has been proven and can be classified as high temperature. The data is well documented and it is supported by the result from the drillings.

The element upflow-outflow is clearly identified by surface and downhole geochemistry data such as from analyses of major cation and anion, isotope and gas. The upflow and outflow zone in some part of the field has been proved by drilling.

The area extent of upflow-outflow zone element has been well delineated by isothermal contour from temperature drilling data, resistivity anomaly from DC-resistivity and MT data and major cation-anion and stable isotope from water samples.

4. CASE STUDY IN GALUNGGUNG FIELD – THE GREEN FIELD PROSPECT

Galunggung is a volcano that last erupted in 1983. According to Bronto (1989), this 30 years ago eruption is a plinian eruption that produced huge volume of pyroclastic fall and flow. The pyroclastic product cover the existing thermal surface manifestation that emerge on the flank of volcano before the eruption. Nowadays, the active thermal manifestation in Galunggung field is very limited. The dominant surface manifestation is a warm to hot streams that flow on the south east flank of volcanoes. The streams receive hot water that seeps along its creek through the contact between pyroclastic breccias flow unit that overlain the older pyroclastic deposit. Other two warm springs appear about 20 to 25 km to the south of the volcano are suspected as the outflow of Galunggung geothermal system (KESDM-EBTKE, 2012). No other surface manifestation either passive or active manifestation are found in this area. This limited surface manifestation suggests that Galunggung is a hidden geothermal system. The current survey has completed about 300 point measurement of Gravity and Magnetic, with spacing between 1-2 km. Whereas the MT survey has not given the result yet, because it is still on progress.

Heat source of this prospect is expected to be associated with Young Galunggung Volcano. This give probability value of unfavorable because it is beyond the limit of favorable age of volcano for heat source, that is between 50 000 to 250 000 year ago (Wohlets and Heiken, 1992.). The young or old volcanic cone has volume greater than 50 km2 which give probability of heat source occurrence encouraging. The proximity of reservoir is unknown because the geophysical result from Gravity and Geomagnetic survey is yet to be able to confirm the exact anomaly associated with heat source and reservoir from the existing 3 anomalies. This gives the probability occurrence value of proximity to reservoir become neutral.

The reservoir temperature from geothermometer give encouraging value, because it is calculated from reliable data and supported by the analogue concept that volcanic associated geothermal system might have high temperature characteristics. The high sulfate and Na-chloride content in the streams suggest high temperature and boiling that release volcanic gas that condense (condensed volcanic gas?) to produce high sulfate in the water (KESDM-EBTKE, 2012). Other reservoir rock and fluid properties element are unknown because no data are available, due to unfinished exploration program. Thus, the other reservoir rock and fluid properties are taken from analogue model from other similar field in the world. Therefore, all the probability occurrence of these elements are assigned the value neutral.

The limited manifestation in this area give very small calculation of heat loss. However we may expect that heat loss can be greater because it is associated with volcano, but no other data support this suggestion. Thus this elements has probability value of questionable. The current exploration program is still unable to delineate the exact the upflow-out flow zone and its area extent. Although some suspected anomalies occur in this area, but it need further integration with geological data to confirm the interpretation of upflow-outflow zone . Thus, these elements has probability of neutral.

5. RISK CALCULATION AND ASSESSMENT

The summary of probability value assigned for every factor and element for Patuha and Galunggung Fields are shown in Table 3 and Table 4, respectively.

For Patuha Field, since the weakest elements determine the risk of the factors, therefore the probability Occurrence of Heat Source (Pheatsource), Reservoir (Preservoir) and Recharge-Discharge (Precharge-discharge) are 0.6, 0.5, and 0.9 respectively. The computed Geology Success (Pg) is 0.270. Refering to Risk Classification Value on Table 5 by Otis and Scheiderman (1997), this Geology Success value is classified as Moderate to Low Risk.

On the contrary, for Galunggung Field (see Table 4), it has Probability Occurrence of Heat Source (Pheatsource), Reservoir (Preservoir) and Recharge-Discharge (Precharge-discharge) are 0.3, 0.5, and 0.4 respectively. The computed Geology Success (Pg) is 0.06. Refering to Risk Classification Value on Table 5 by Otis and Scheiderman (1997), this Geology Success value is classified as Very High Risk.

Tabel 3: Assessment of Probability of Geologic Occurrence of Patuha Field

GEOLOGIC RISK PATUHA FIELD

No	Geologic Factor / Elements	Unfavorable	Questionable	Neutral	Encouraging	Favorable
I	**Heat Source**	$P_{heatsource}$ = **0.6**				
I.1.	Volume (Geometry)				0.6	
I.2	Age					0.7
I.3	Proximity to reservoir					0.8
II	**Reservoir**	$P_{reservoir}$ = **0.5**				
	Rock Properties					
II.1	Area					0.9
II.2	Tickness					0.7
II.3	Cap Rock					0.9
II.4	Porosity-Permeability				0.6	
II.5	Density			0.5		
II.6	Thermal conductivity			0.5		
	Fluid Properties					
II.7	Temperature					0.9
II.8	Fluid phase					0.8
II.9	Saturation				0.6	
II.10	Fluid Density				0.6	
II.11	NCG				0.6	
II.12	pH				0.6	
II.13	Scaling			0.5		
III	**Recharge-Discharge**	$P_{recharge-discharge}$ = **0.9**				
III.1	Heat Loss					0.9
III.2	Upflow-Outflow Zone					0.9
III.3	Area Extent					0.9

Probability of Geology Success (P_g) = $P_{heatsource}$ X $P_{reservoir}$ X $P_{recharge-discharge}$ = **0.6 x 0.5 x 0.9 = 0.270**

6. DISCUSSION AND CONCLUDING REMARK

Using the same criteria for well develop and green geothermal field, the geologic risk were quantified. The value of probability geologic success (Pg) were then determined. This probability of geologic success can also show how much risk that the geothermal operator facing. The smaller the probability (Pg) value the higher the risk, and the greater the probability (Pg), the lower the risk. The total risk are determined by the lowest value of the probability occurrence of at least one element. The element(s) must be considered for further exploration program. For example, for the age of heat source in Galunggung Prospect which is only 0.3 (Table 4), the next exploration program may need to change the concept of exploration, which will not look for Young Galunggung Volcano as heat source, instead to seek for older Galunggung volcano or its adjacent volcano.

This study uses the geologic factor and elements which is determined by the expert based on their experience. The type of geologic factor and elements need to be refined and defined by the team of expert and must be tested in various field with similar geothermal type in order to have at least standard or acceptable agreement, thus creating a standardized method to compare or to weigh between geothermal field prospect. This task becomes a challenge of this research.

It is also necessary to have an agreement among geothermal expert about what data and its characteristic to be considered as direct or indirect (i.e. analogue) for an assessment of favorable, encouraging, neutral, questionable, and unfavorable. The criteria for assigning value of probability occurrence for every elements is also need to be determined reasonably. This is because it only took one very low value of geologic element (eg. value of 0.3 for Galunggung heat source age, see Table 4) to diminish the value of other probability (0.5 and o.6 for proximity to reservoir and volume, respectively), resulting the probability of 0.3 for heat source. Furthermore, the final probability of geologic success is a result of multiplication of all the probability occurrence of all geologic factors. In this research we use only three geologic factor (heat source, reservoir, and recharge-discharge) and produced the geologic risk 0.060 and 0.270, for Galunggung and Patuha geothermal field, respectively. It is obvious that if the geologic factors are many, the result of the multiplication will be very small and difficult to assess in term of the type of risk that we are facing and how big is the risk. Thus a research on how much is the number of geologic factor and how to assign the value is necessary.

The final Probability of Geologic Success value (Table 5) must translate into associated exploration stage or field development. The two assessments above demonstrate the two Probability of Geologic Success from two significantly different fields; green fields and non-productive but well developed fields. For example, in frontier area for petroleum exploration, average Pg = 0.05 is already considered as good result in term of geologic success (Otis and Schneidermann, 1997), whereas in mineral exploration average Pg = 0.01 to 0.05 for brownfields exploration is considered typical industry success (Kreuzer, 2007 in Kreuzer et.al., 2008). In this study for geothermal, we adopt Otis' scale in Table 5, the geologic success for very high risk area, where average Pg = 0.05. Despite of lack of evidence or studies, this value may correspond with first exploration well to test the new occurrence of geothermal system in an unproved area (Suryantini, 2011).

Although has not been tested yet, we suspect that a producing geothermal field will have very low risk with Probability of Geologic Success value about 0.75. However, the effect and cause of lower probability of elements within a geologic factor has to be studied further. Sometimes a producing field need to conduct a step out exploration program or have to drill a slightly outside the current reservoir boundary where the risk is expected to be higher. For such kind of condition, this method is also need to be tested.

Nevertheless, in general, geologic risk in geothermal exploration can be quantified with the method adopted from oil prospecting as it is shown in this study, but some modification must be studied further in detailed to make the method more applicable in geothermal exploration.

Tabel 4: Assessment of Probability of Geologic Occurrence of Galunggung Field

GEOLOGIC RISK GALUNGGUNG FIELD

No	Geologic Factor / Elements	Unfavorable	Questionable	Neutral	Encouraging	Favorable
I	**Heat Source**	$P_{heatsource}$ = **0.3**				
I.1.	Volume (Geometry)				0.6	
I.2	Age	0.3				
I.3	Proximity to reservoir			0.5		
II	**Reservoir**	$P_{reservoir}$ = **0.5**				
	Rock Properties					
II.1	Area			0.5		
II.2	Tickness			0.5		
II.3	Cap Rock			0.5		
II.4	Porosity-Permeability			0.5		
II.5	Density			0.5		
II.6	Thermal conductivity			0.5		
	Fluid Properties					
II.7	Temperature				0.6	
II.8	Fluid phase			0.5		
II.9	Saturation			0.5		
II.10	Fluid Density			0.5		
II.11	NCG			0.5		
II.12	pH			0.5		
II.13	Scaling			0.5		
III	**Recharge-Discharge**	$P_{recharge\text{-}discharge}$ = **0.4**				
III.1	Heat Loss		0.4			
III.2	Upflow-Outflow Zone			0.5		
III.3	Area Extent			0.5		
Probability of Geology Success (P_g) = $P_{heatsource}$ X $P_{reservoir}$ X $P_{recharge\text{-}discharge}$ =		**0.3 x 0.5 x 0.4 = 0.060**				

Tabel 5: Assessment of Probability of Geologic Occurrence of Galunggung Field

Very Low Risk		Low Risk		Moderate Risk		High Risk		Very High Risk
	1:2		1:4		1:8		1:16	
Avg P_g = 0.75		Avg P_g = 0.375		Avg P_g = 0.183		Avg P_g = 0.092		Avg P_g = 0.05

P_g : Probability of Geological Success

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