A New Mechanism in Determining the Number of Geothermal Wells for Power Plant Development Using Stochastic Method

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Abstract. The number of geothermal wells (production, injection, make-up) should be calculated carefully to get the optimum values for the technical aspect of power plant development. However, the method for calculating the number of wells has been used is a deterministic approach that involves only a single value for every parameter. Since the result of this method is a single value, it cannot capture the uncertainties of the field parameters. Therefore, this paper proposed the newest method that applied 2-level full factorial design of experiment approach with the help from Minitab software to cover the uncertainties of the field parameters and to produce the probabilistic number of wells in combination with Monte Carlo Simulation. The proposed method has been successfully used to calculate the number of wells in the case study of Karaha-Talaga Bodas field. Based on the study, the most significant factors for determining the number of production and injection wells are the fluid enthalpy and total mass flow rate, whereas for the make-up wells number are the decline rate and make-up well capacity. 5 production wells, 1 injection well, and 4 make-up wells are the minimum requirement number of wells that should be drilled for generating 30 MW power plant capacity in 30 years.

1. Introduction
The production, injection, and make-up wells are required for supporting the geothermal power plant. The number of these wells are affected by the field properties, such as the fluid enthalpy, total mass flow rate, injectivity, decline rate, make-up well capacity, and the others. However, the field properties had varying values or in other words had uncertainty [1]. This uncertainty made the number of geothermal wells should be calculated carefully to avoid the bias of the varying data of the field properties.

The estimation process of the geothermal wells number is conducted in the feasibility study. The risk level of these processes is affected by the field properties, such as the fluid enthalpy, total mass flow rate, injectivity, decline rate, make-up well capacity, and the others. However, the field properties had varying values or in other words had uncertainty [1]. This uncertainty made the number of geothermal wells should be calculated carefully to avoid the bias of the varying data of the field properties.

The risk level of the feasibility study or FS Planning is moderate [2]. All data and the uncertainties from the previous phases should be processed in this phase. Since there are the exploitable reserve, development strategy, and the financial flow of the project in the feasibility study document [3], the economics will be very influenced by the number of geothermal wells. Also, it is supported by the previous study that stated that the 40% portion of the whole geothermal project investment are from the drilling cost [4]. Therefore, the appropriate method for determining the geothermal well number should be established for reducing the risk of development strategy on the next stages.
The risk level in the feasibility study is made worse by the usage of deterministic method for estimating the number of geothermal wells. The single value of fluid enthalpy, total mass flow rate, and other properties are utilized for determining the number of production and injection wells [5]. Also, the estimated production decline results on single value due to the use of single value for every parameter [6]. The use of a single value of every parameter above can lead to the individual value of the number of geothermal wells that also have high uncertainty.

Therefore, the stochastic method that applied the probabilistic approach and experimental design is proposed in this paper. The stochastic method can be applied to the calculation of the number of geothermal wells to overcome the effect of uncertainty. The application of experimental design and probabilistic approach had been widely used in the geothermal industry. The stochastic method had been utilized in quantifying the uncertainty of subsurface properties [7]. Application of experimental design and response surface method was established in a preliminary result of geothermal resource assessment [8]. The location of a wellbore in the geothermal area had been optimized by experimental design [9]. The experimental design method was used in assessing the reserve or “field size” in a geothermal greenfield [10]. The utilization of Placket-Burman design was also applied in uncertainty parameters reservoir vapor-dominated [11]. The probabilistic approach had been employed in geothermal backpressure turbine application [12]. The implementation of experimental design was done in Ciwidey resource assessment [13]. The experimental design had been implanted in 3D natural state model for Karaha-Talaga Bodas geothermal area [14].

The stochastic method that applied 2-level full factorial experimental design and probabilistic approach are promoted in this paper to minimize the risk of the field properties uncertainty. The purpose of experimental design is bringing new considerations for the calculation of the geothermal wells number. The significant parameters for the calculation of each well will be observed in the experimental design. The application of probabilistic approach is for covering the varying values of every parameter. The result of this probabilistic method is the range number or P10, P50, P90 number of each well. Moreover, this stochastic method is applied in a case study of Karaha-Talaga Bodas geothermal area. Besides of the brine underlined steam system of the field, Karaha-Talaga Bodas is already operating, so that there are sufficient data from the published papers that can be used as the references for this study.

Based on several reasons above, the objectives of this study are the followings.

1. To establish a method using the probabilistic approach for estimating the number of geothermal wells (production, injection, and make-up) in a geothermal area.
2. To determine the most significant factor in determining the number of geothermal wells.
3. To estimate the range of well number needed in a geothermal area.

2. Basic Theory

The stochastic method applied in this paper is the combination of experimental design and monte carlo simulation. The experimental design was founded in the 1920s and 1930s by Ronald A. Fisher [15]. Design of experiment or also known as the experimental design is a thorough process of the test in which the deliberate modifications are applied, and the variations in response variables are observed. Monte Carlo Simulation is the method that implements the statistical sampling techniques for gaining the probabilistic approximation of the mathematical model by employing the random numbers as the input to the simulation [16].

The main point of the experimental design is to determine the independent variable, dependent variable, and nuisance effect and to find out in what way these variables interact. Therefore, the result is the causal relationship between the independent and dependent variables [17]. The example of proxy equation is shown in equation 1. y is the response or dependent variable. A, B, C, D, E are the dependent variables. AB is the combination of A and B variables. α is the coefficient that represents the significance of the factors. The bigger the α is, the more significant the factor regardless of the coefficient sign.
\[ y = \alpha_0 + \alpha_1 A + \alpha_2 B + \alpha_3 C + \alpha_4 D + \alpha_5 E + \alpha_6 AB + \cdots \]  

There is a response variable in the experimental design. This variable is provided by the number of geothermal wells with the conventional method or deterministic method. The deterministic formula for production well and injection well is derived from the thermodynamics process [5]. The equation 2 and equation 3 are the deterministic equation used as the response variable for the experimental design study in this paper.

\[ n_{\text{prod}} = \frac{1000 w_{pp}}{m_{\text{steam}} (h_i - h_o) \eta} \]  

\[ n_{\text{inj}} = \frac{m_{\text{brine}} n_{\text{prod}}}{IC} \]

\( w_{pp} \) is the power plant capacity in MW. \( m_{\text{steam}} \) is the steam mass rate into the turbine (kg/s). \( h_{i/o} \) is the input/output of the fluid enthalpy to/from the turbine. \( \eta \) is the turbine efficiency (%). \( m_{\text{brine}} \) is the brine mass rate from one production well (kg/s). \( n_{\text{prod}} \) is the total number of production well in the field. IC is the injection capacity or the injectivity of the injection well (kg/s).

The number of make-up well is estimated from the production decline. The determination of production decline in the geothermal industry is adopted from the decline model of oil and gas industry [18]. There are exponential, hyperbolic, and harmonic decline curve that were proposed by Arps [6]. However, the basic equation of decline curve is shown in equation 4. The modified decline curve of exponential and harmonic for the geothermal purpose is shown in equation 5 and equation 6.

\[ \frac{1}{q} \frac{dq}{dt} = -b q^d \]  

\( q \) is the production rate. \( t \) is the production time. \( b \) is the production decline. \( d \) is the constant that determines the decline curve model. When \( d=0 \), \( 0<d<1 \), and \( d=1 \), the result for each condition is the exponential, hyperbolic, and harmonic. The decline curves will be used in this study are the exponential and harmonic decline curve for the simplicity of \( d \) values. However, if the value of \( d \) for the hyperbolic curve is known, the hyperbolic curve could be used.

\[ MW_{\text{existing}} = MW_i \times e^{-bt} \]  

\[ MW_{\text{existing}} = \frac{MW_i}{(1 + b t)} \]

\( MW_{\text{existing}} \) is the current capacity generated by the power plant (MW), and \( MW_i \) is the initial power plant capacity (MW).

3. Methodology
Based on Figure 1, the first step of this study is determining the observed factors or parameters as the independent variables. The factors with high uncertainty must be screened in this step. Then, the 2-level full factorial is applied to the observed factors. Since it is 2-level, the maximum and minimum values for each factor is determined. The combination of all observed parameters will be resulted by Minitab™ (statistical software). All combinations are employed as the input for the equation of response variable. After applying the experimental design in Minitab, the significance of all factors will be generated by the Pareto chart. Not only the significance but also the proxy equations that show the causal relationship between the independent and dependent variables are the result of the
experimental design. The combination of this proxy equation and the Monte Carlo Simulation is the last step to achieve the P10, P50, and P90 number of geothermal wells (production, injection, and make-up) for 30 years production of 30 MW power plant capacity. P10 number is the minimum number of wells needed in the field.

![Research Methodology Diagram](Image)

**Figure 1.** Research methodology.

4. Field Data

4.1. Field Overview
Karaha-Talaga Bodas (KTB) geothermal area is the partially vapor-dominated area located in West Java, Indonesia [19]. The brine underlined steam cap system made this area a lot of uncertainty. The reservoir temperature of this area is in the range of 250-350°C [20]. There are 14 wells that had been drilled in KTB until 2009 [21]. The geoscience study and exploration drilling showed that there is the steam cap extension of Karaha-Talaga Bodas from the south until north part of this field [22]. The south part is the location where the thickest steam cap is.

Based on the latest study, the potential reserve of KTB is at least 116 MW [23]. The Energy and Natural Resources Ministry of Indonesia showed that the potential reserve of Karaha is 30 MW, and Talaga’s is 80 MW [24]. However, the previous operator which was Karaha Talaga Bodas company issued a great different potential reserve. The result of Karaha Talaga Bodas company was 260 MW [1]. The uncertainty of this field is supported by this different result of potential reserve. The previous operator was quite optimistic than the latest study. KTB is currently operated by Pertamina Geothermal Energy with the contract capacity of 220 MW [25]. The commercial operation date had been conducted on April 6th, 2018 [26].

4.2. Well Data Analysis
The following data in Table 1 are the result of well testing in Karaha-Talaga Bodas Geothermal Field. The Karaha part is in the north and Talaga-Bodas part is in the south region of the area [22]. From the data, it can be observed that the Karaha part of this field is a liquid-dominated area. Meanwhile, the Talaga Bodas part is a vapor-dominated area. Therefore, the more north (Karaha), the more liquid-dominated can be found in this field.

K-33, T-2, and T-8 well are the core holes. Therefore the three wells are not considered as the data for the calculation of the number of development wells. KRH 2-1RD data cannot be used as productive well. It is due to the wellhead pressure is too low to be commercialized. The same thing has also happened in KRH 3-1ST. Besides, the acidity and salinity of this well is relatively high. The chloride content of this well is about 40,780 mg/L, and the pH is about 2.2 [1]. The pH of TLG 1-1ST2 is also low (< 3). NCG (Non-Condensable Gas) content of TLG 2-1 is also too high (± 17 wt%). The condition of high salinity, high acidity, and high NCG content cannot be considered as proven area
Therefore, the data that are used for the experimental design is from KRH 4-1, KRH 5-1, and TLG 3-1.

### Table 1. Karaha-Talaga Bodas well testing result [1].

| Well    | Well Size | Results                       | WHP (bara) | Total Mass Rate (kg/s) | Enthalpy (kJ/kg) |
|---------|-----------|-------------------------------|------------|------------------------|------------------|
| KRH 1-1ST | Regular   | Not sustain to flow           |            | 100.8                  | 1163             |
| KRH 2-1RD | Regular   | 4                             | 37.8       | 34.6                   | 2210             |
| KRH 3-1ST | Regular   | 8                             | 25.5       | 2.4                    | 2035             |
| KRH 4-1  | Regular   | No flow test conducted        |            |                        |                  |
| KRH 5-1  | Regular   | 8                             | 1396       |                        |                  |
| K-33     | Slim      | 10                            | 2559       |                        |                  |
| TLG 1-1ST2 | Regular  | 10                            | 2559       |                        |                  |
| TLG 2-1  | Regular   | 8                             | 2675       |                        |                  |
| TLG 3-1  | Regular   | 8                             | 2675       |                        |                  |
| T-2      | Slim      | 16                            | 2675       |                        |                  |
| T-8      | Slim      | 8                             | 2652       |                        |                  |

### 5. Result and Discussion

#### 5.1. Production Well

There are four factors to observe in production wells number calculation. They are the enthalpy ($h$), total mass flow rate ($\dot{m}_{tot}$), turbine efficiency ($\eta$), and condenser pressure ($CP$). The minimum and maximum values of the four factors above are shown in Table 2. The maximum and minimum values of enthalpy are from well-testing data. It means the well testing should be applied first on the field so that this method can be applied. The same thing has occurred in the total mass flow rate. The isentropic efficiency of the geothermal turbine had been demonstrated with the result in the range of 81% until 85% [28]. The variations in turbine efficiency can occur due to the deviation from isentropic behavior and the presence of moisture (mist) in the steam expansion process in the turbine [29]. Condenser pressure is in the range of common usage in the geothermal field. However, 0.12 bara is the applied condenser pressure in Karaha-Talaga Bodas [30]. The value of 0.085 bara is the variation for the condenser pressure to see the effect of condenser pressure to the production well number.

### Table 2. Observed variables for production well.

| Factors                    | Min (-1) | Max (1) |
|----------------------------|----------|---------|
| Enthalpy (kJ/kg)           | 1396     | 2559    |
| Total Mass Flow Rate (kg/s)| 15.75    | 34.65   |
| Turbine Efficiency         | 0.81     | 0.85    |
| Condenser Pressure (bara)  | 0.085    | 0.12    |

To analyze these four factors above, the 2-level (maximum and minimum) full factorial is applied with the help of Minitab Software. The total run was 16 runs for 30 MW development capacity in 30 years. The design and result of calculation are shown in Table 3. From the table, there are standard order and run order. The standard order is the fulfillment of random interaction between factors and
the avoidance of order-dependence interaction. Otherwise, run order is the sequence of calculation between the variations of the factors involved.

Table 3. 2-Level Full Factorial Design and the result of the production wells number Experimental Design for 30 MW plan capacity without DSR.

| Std Order | Run Order | Enthalpy (kJ/kg) | Total mass flow rate (kg/s) | Turbine Efficiency (%) | Condenser Pressure (bara) | The Number of Production Wells |
|-----------|-----------|------------------|-----------------------------|------------------------|--------------------------|--------------------------------|
| 8         | 1         | 1                | 1                           | 1                      | -1                       | 2                              |
| 14        | 2         | 1                | -1                          | 1                      | 1                        | 5                              |
| 2         | 3         | 1                | -1                          | -1                     | 1                        | 5                              |
| 15        | 4         | -1               | 1                           | 1                      | 1                        | 5                              |
| 10        | 5         | 1                | -1                          | -1                     | 1                        | 5                              |
| 3         | 6         | -1               | 1                           | -1                     | 1                        | 5                              |
| 12        | 7         | 1                | -1                          | 1                      | -1                       | 2                              |
| 4         | 8         | 1                | 1                           | -1                     | -1                       | 2                              |
| 11        | 9         | -1               | 1                           | -1                     | 1                        | 6                              |
| 16        | 10        | 1                | 1                           | 1                      | 1                        | 2                              |
| 9         | 11        | -1               | -1                          | -1                     | 1                        | 12                             |
| 6         | 12        | 1                | -1                          | 1                      | -1                       | 4                              |
| 1         | 13        | -1               | -1                          | -1                     | -1                       | 11                             |
| 13        | 14        | -1               | -1                          | 1                      | 1                        | 11                             |
| 7         | 15        | -1               | 1                           | 1                      | -1                       | 5                              |
| 5         | 16        | -1               | -1                          | 1                      | -1                       | 11                             |

Equation 2 that had been discussed above was implemented in the calculation of the production wells number. Besides, there are other assumptions for the field design of Karaha-Talaga Bodas. The wellhead pressure is assumed to be at 8 bara, and the turbine inlet pressure is considered as much as 6.8 bara. These assumptions are based on the project design of Karaha-Talaga Bodas [30]. Wellhead pressure and turbine inlet pressure are supposed as constant variables during the production period. It is because of the low possibility of change for these two variables. Also, the process from the reservoir until the turbine is assumed as the isenthalpic process and the turbine process is assumed as the isentropic process.

Figure 2. Pareto chart result of the production well Experimental Design for 30 MW power plant capacity without DSR.
The significance of each factor for the response variable is shown in the Pareto chart of Figure 2. Besides, the proxy equation (polynomial equation) that described the relationship and interaction between the factors in affecting the response variable is shown in equation 7. The proxy equation had included all factors and all 2-way interactions between those four factors. Based on the Pareto chart, the most significant factor is the fluid enthalpy ($h$), and the least one is the turbine efficiency ($\eta$). It means the slight change of fluid enthalpy will result on the great impact to the number of production wells. The same result is also exhibited by the proxy equation. The biggest coefficient of the fluid enthalpy is the result of its significance. The $R^2$ value of equation 7 is 99.98%. $R^2$ is the percentage of the variations that are explained by the model [31]. The higher the value of $R^2$ is better the result of the model. The standard deviation (S) of the equation is 0.07. S value is the representation of the standard deviation of the distance between the data values and the fitted values. The fitted values are the results of the proxy equation. The lower S values are more representative of the model.

\[
30 \, MW_{\text{prod}} = 5.38 - 2.44h - 2.02m_{\text{tot}} - 0.16\eta + 0.17CP + 0.91(h)(m_{\text{tot}}) \\
+ 0.07(h)(\eta) - 0.08(h)(CP) + 0.06(m_{\text{tot}})(\eta) - 0.07(m_{\text{tot}})(CP) \\
- 0.01(\eta)(CP)
\] (7)

Equation 7 is combined with Monte Carlo Simulation which is run by 10000 iterations. The result is the frequency distributions of all values that are possible to be the number of production wells for 30 MW development capacity in 30 years. The Monte Carlo Simulation result can be seen in Figure 3. Based on the result of Monte Carlo Simulation, at least there must be 4 production wells in Karaha-Talaga Bodas to generate 30 MW for 30 years. However, it can be increased until 8 wells due to the non-desired condition in the field.

5.2. Injection Well
The experimental design for the injection well is done with 4 observed factors/parameters. The factors are the fluid enthalpy ($h$), total mass flow rate ($m_{\text{tot}}$), the number of production wells ($n_{\text{prod}}$), and the injection capacity or injectivity (IC). The fluid enthalpy and total mass flow rate are the same as the production well. The number of production wells is based on the result of production well experimental design. Since there is no data of injectivity in Karaha Talaga Bodas, the injection capacity is assumed based on the Patuha and Wayang Windu due to the similarity of the geological and geothermal system between those fields [32] [33].
The same method as before is applied for the injection well experimental design. The 2-level full factorial is utilized. The maximum and minimum values for every parameter can be seen in Table 4. Equation 3 is used as the formula to get the number of injection wells as the response variable. The result of the design of experiment is represented by Equation 8. Based on equation 8, the most significant factors for calculating the number of injection well is the fluid enthalpy. It can be observed by seeing the coefficient of the fluid enthalpy. The change of enthalpy will give the multiple of 1.08 for the result (the largest compared to the other variables). The least significant one is the number of production wells. The $R^2$ and $S$ values of equation 8 are 98.62% and 0.31.

$$30\, MW_{n_{inj}} = 1.46 - 1.08h + 0.55\dot{m}_{tot} + 0.34n_{prod} - 0.42IC - 0.41(h)(\dot{m}_{tot})$$
$$- 0.25(h)(n_{prod}) + 0.31(h)(IC) + 0.13(\dot{m}_{tot})(n_{prod}) - 0.16(\dot{m}_{tot})(IC)$$
$$- 0.09(n_{prod})(IC)$$

Equation 8

Combination with 10000 iterations of Monte Carlo Simulation yields on Figure 4. There must be one injection well for most ideal condition of supporting 30 MW power plant capacity in Karaha-Talaga Bodas. However, the most certain one as the chart showed is 3 injection wells. It is the most non-ideal condition of Karaha-Talaga Bodas’s injection wells.

5.3. Make-Up Well

The conventional method for determining the number of make-up wells is utilizing the production decline estimation with the Arps equation. The example is shown in Figure 5. Because the determination is done in the feasibility study, the reservoir performance of decline rate is based on the estimation. Therefore, the uncertainty will be high if the single-value estimation is applied.
There are three observed factors to conduct the experimental design of make-up well. The factors are the decline rate, decline curve model, and make-up well capacity. The values for every parameter are shown in Table 5.

**Table 5.** Observed variables for Make-Up well.

| Factors                  | Min (-1) | Max (1) |
|--------------------------|----------|---------|
| Decline Model            | Exponential | Harmonic |
| Decline Rate (%/year)    | 1        | 3       |
| Well Capacity (MW)       | 4.4      | 12.9    |

The decline models chosen are the exponential and harmonic decline curve for the simplicity of “d” value and comparing between the effect of these two curves to the make-up well number. The decline rate is based on the average values of vapor dominated geothermal area in Indonesia [33]. Meanwhile for the make-up well capacity, the values are based on the calculation in Table 6. All values are found on Pertamina Project Design and Karaha-Talaga Bodas Well Testing except the turbine efficiency [1] [30]. The turbine efficiency is the average of maximum and minimum values for isentropic turbine efficiency [29]. The combinations for the experimental design are only 8 since only three factors involved here.

**Table 6.** Make-Up well capacity calculation

| WHP (bara) | TIP (bara) | Condenser Pressure (bara) | Turbine Eff | Enthalpy (kJ/kg) | $m_{tot}$ (kg/s) | Steam to turbine (kg/s) | Power Generated (MWe) |
|------------|------------|----------------------------|-------------|------------------|------------------|-------------------------|------------------------|
| 8          | 6.8        | 0.12                       | 0.83        | 2209.7           | 34.65            | 25.41                   | 12.9                   |
| 8          | 6.8        | 0.12                       | 0.83        | 1395.6           | 25.45            | 8.65                    | 4.4                    |
| 8          | 6.8        | 0.12                       | 0.83        | 2558.6           | 15.75            | 14.21                   | 7.2                    |

The result of the experimental design is depicted by the proxy equation in equation 9. Based on equation 9, the most significant factors are decline rate and the make-up well capacity for determining the number of make-up well number in Karaha-Talaga Bodas. The $R^2$ and $S$ values for this equation are 100% and 0. It means the confidence-level of equation 9 is considered high. The combination of the proxy equation with 10000 repetitions of Monte Carlo Simulation result are shown on Figure 6. At least three make-up wells are required for 30 years production of 30 MW in Karaha-Talaga Bodas and it can increase until five wells if the worst case happened in the field.
$$30 \text{ MW}_{\text{MU}} = 3.5 + 1.5D_{\text{Rate}} - 1.5\text{Well}_\text{Cap} - 0.5(D_{\text{Rate}})(\text{Well}_\text{Cap})$$

Figure 6. Monte Carlo Simulation result of Make-Up wells number for 30 years production of 30 MW capacity in Karaha-Talaga Bodas.

5.4. Comparison with Other Method
The validation is needed for proving the robustness of this method. The previous study with the numerical simulation method is employed here [34]. The comparison can be observed in Table 7. All results of numerical simulation are included in the range of the stochastic method’s result. It means that this stochastic method and the reservoir simulation can be complemented to each other. Not only the numerical simulation result but also the field condition result is also in the range of the stochastic method’s result. This current field condition result is shown in Table 7 [35].

| Well Type        | Percentile | Stochastic Method | Reservoir Simulation | Field Condition |
|------------------|------------|-------------------|----------------------|-----------------|
| Production Well  | P10        | 4                 | 5                    | 5               |
|                  | P50        | 6                 |                      |                 |
|                  | P90        | 8                 |                      |                 |
| Injection Well   | P10        | 1                 | 1                    | 1               |
|                  | P50        | 2                 |                      |                 |
|                  | P90        | 3                 |                      |                 |
| Make-Up Well     | P10        | 3                 |                      | Not Established |
|                  | P50        | 4                 | 3                    | Established     |
|                  | P90        | 5                 |                      | Yet             |

The results of field condition and reservoir simulation are in the range of stochastic method’s outcome. It means that the method had been validated by the field result. Even though it cannot be generalized to all geothermal field, but it is usable for Karaha-Talaga Bodas geothermal area and is legit to use this method on the other geothermal areas.

6. Conclusion
The new method for estimating the number of geothermal wells (production, injection, and make-up) had been established. Since the method had been validated by the field condition of KTB, it can be stated that this new method is promising. The discoveries based on the study in this paper are the followings.

1. The most significant factors for determining the number of production and injection wells in Karaha-Talaga Bodas are the same; they are the fluid enthalpy and the total mass flow rate...
from the wells. Meanwhile the decline rate and the make-up well capacity are the most considerable factors for reckoning the number of make-up wells in Karaha-Talaga Bodas.

2. 4 production wells, 1 injection well, and 3 make-up wells are the minimum requirement for developing 30 MW power plant capacity for 30 years in Karaha-Talaga Bodas.

7. Recommendation
The future works can be conducted to improve the method. The study in this paper can be optimized by considering the points as followings.

1. The data must be the most updated one. Since the method is using statistical approach, the quality of data is very important for the better result.

2. Since the method only involved the minimum and maximum number, the range can be too wide. To cover the middle value for every variable, the other experimental design and response surface method such as 3-level full factorial, Central Composite Design, Box-Behnken Design, and the other can be applied to this study as a comparison to the two-level full factorial design. The comparison can be made by utilizing the residual plot, error, standard deviation, and R² of each experimental design or surface response method.

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