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Probabilistic Resource Assessment of The Ulumbu Geothermal Field, East Nusa Tenggara, Indonesia

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Abstract - A resource assessment of the Ulumbu Geothermal Field, East Nusa Tenggara, Indonesia, is proposed here. The fundamental issue of reserve estimation is determining the optimum capacity to be installed (field size) that affects the decision-making in geothermal projects. The reservoir numerical model and heat stored method are the most appropriate tools for geothermal resource assessment. Therefore, the hybrid numerical simulation and heat stored methods, coupled with the probabilistic approach, are applied to Ulumbu. Based on the calibrated numerical model, the estimation of the reservoir is divided into the steam zone and liquid reservoir. The energy reserve of the Ulumbu is estimated by Monte Carlo simulation with the results P10-P50-P90 are 71 MWe, 95 MWe, and 127 MWe, respectively.

Keywords: Ulumbu, reservoir numerical model, heat stored, Monte Carlo, probabilistic resource assessment

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Introduction

The Ulumbu geothermal field is located in Manggarai Regency, East Nusa Tenggara, Indonesia, as shown in Figure 1. It is owned by P.T. PLN (Persero) with a concession area around 10 km^2. The field has been producing electricity from four units, having a total capacity of 10 MWe. The Ulumbu power plant plans to increase the electricity production by adding two more units having a total capacity of 2×20 MW; then, further assessment of the reservoir needs to be carried out. An integrated reservoir study is needed to estimate the reservoir power generation capacity, to increase the understanding of the reservoir characteristics, and to determine an optimum development scenario. The application of a numerical reservoir model in planning and managing a geothermal field has been a widespread practice as more than a hundred geothermal fields that have been modelled worldwide (O'Sullivan *et al*., 2001).

The integrated reservoir studies using reservoir simulation had been carried out by several researchers, a greenfield and brownfield of geothermal fields. Several geothermal greenfield numerical modelling, not yet been developed for production, have been carried out, such as Atadei (Supijo *et al*., 2019a, 2019b, 2018; Pratama *et al*., 2020; Supijo *et al.*, 2020), Danau Ranau (Afiat *et al*., 2021), Cisolok-Cisukarame (Sumartha *et al*.,

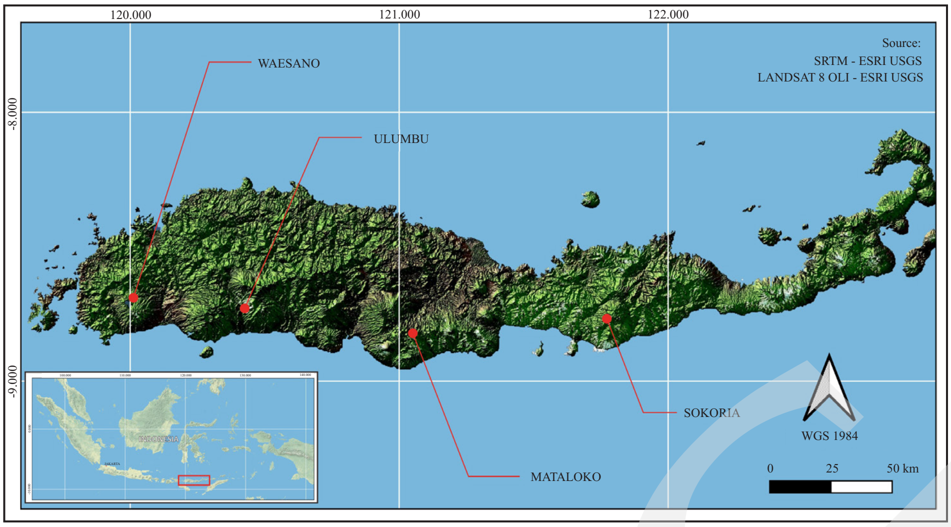

Figure 1. Location of Ulumbu geothermal field in Flores Island.

2020), Ungaran (Assiddiqy *et al*., 2021), Songa-Wayaua (Hasbi *et al*., 2020), and Arjuno-Welirang (Putra *et al*., 2019). The greenfield numerical model provides a piece of useful information for consistency with the conceptual model. Reservoir numerical simulation, at the exploration state with limited data available, is unlikely to give a more realistic long-term production than more straightforward volumetric methods. However, it has a value at that stage, but this method might be the best for checking the consistency or update the conceptual model.

On the other side, several geothermal fields producing brownfield in Indonesia have been modelled, such as Sibayak (Atmojo *et al*., 2001), Kamojang (Zuhro, 2004; Suryadarma *et al*., 2010), Darajat (Alamsyah *et al*., 2005; Hoang *et al*., 2005), Lahendong (Koestono *et al*., 2010), Wayang Windu (Mulyadi and Ashat, 2011), Dieng (Sirait *et al*., 2015; Ashat *et al*., 2019c), Awibengkok (Pasikki *et al*., 2016), Muara Laboh (Situmorang *et al*., 2016), Sarulla (Marjuwan *et al*., 2016; Nizami *et al*., 2016), Patuha (Firdaus *et al*., 2016; Ashat *et al*., 2018; Ashat and Pratama, 2018; 2019a, 2019b, 2019d; Pratama *et al*., 2021), Karaha Telaga Bodas (Prabata *et al*., 2017, 2019; Sutopo *et al*., 2019), Ulumbu (Kurniawan *et al*., 2017, 2018a, 2019), Sorik Marapi (Mulyani *et al*., 2019), Mataloko (Pradhipta *et al*., 2019; Jatmiko *et al*., 2021), Tompaso (Lesmana *et al*., 2019, 2021), Lumut Balai (Hamdani *et al*., 2020). Reservoir simulation is the most applicable method for estimating reserves of geothermal fields. The output of numerical model could be used to estimate the Ulumbu geothermal reserves with heat stored method coupled with Monte Carlo simulation.

The process of building a numerical reservoir model for a project at the early exploitation stage is essential, and the estimation of the heat stored method could be useful (Sarmiento and Björnsson, 2007; Sarmiento and Steingrímsson, 2013). The numerical reservoir model could be used to decide an optimum development scenario for the Ulumbu geothermal field (Kurniawan *et al*., 2017, 2018a, 2019). Therefore, this study aimed to estimate the energy reserve of the Ulumbu geothermal field using the heat stored method coupled with Monte Carlo simulation based on the output from a natural state calibration of the Ulumbu numerical model.

Material and Methods

Ulumbu Numerical Model

The Ulumbu conceptual models provide a full description of the structure and nature of the Ulumbu geothermal system. The models were built from integrated multidisciplinary geological, geochemical, geophysical, and well data. Figure 2 shows the conceptual model of the field by using a slice plan NE–SW. It represents the components of a geothermal system such as reservoir, heat source, caprock, recharge and discharge areas.

The latest model by Kurniawan (Kurniawan *et al.*, 2019) was used in this study. The natural state model modified the model structure and increased the validation accuracy through better well temperature matching and better conceptual model representation. In this study, only temperature profiles were considered as no actual pressure profiles were available. Figure 3 indicates a good matching between the model temperature and the actual data.

The iso-temperature profile and steam cap zone above the deep liquid reservoir are shown in Figures 4 and 5. This reservoir type is similar to several types of research in the two-phase geothermal field (Pratama and Saptadji, 2016, 2018, 2021; Prabata *et al.*, 2019; Hamdani *et al.*, 2020). The model temperature distribution and mass vector show a good correspondence with the conceptual model. The mass vectors also show the location of the upflow and outflow zones of the geothermal system. Conceptual model and natural state model, in terms of mass flow, show a good correlation, indicated by the direction of fluid flow and the location of upflow and outflow on the model. The upflow zone is between the Poco Rii depression and Poco Leok, while the outflow zone is towards the west. The fluid flow direction from the west towards the east reservoir area is indicated as the recharged area based on the numerical model. Therefore, the result of the Ulumbu numerical

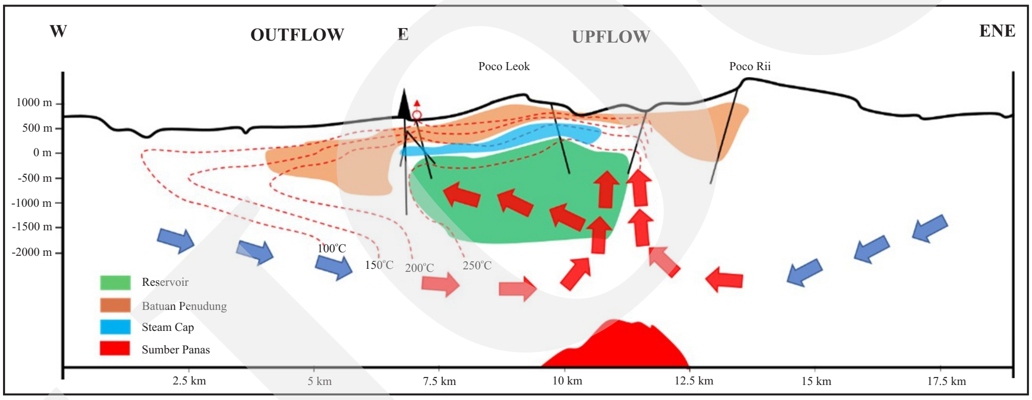

Figure 2. Conceptual model of the Ulumbu geothermal field (Kurniawan *et al.*, 2019).

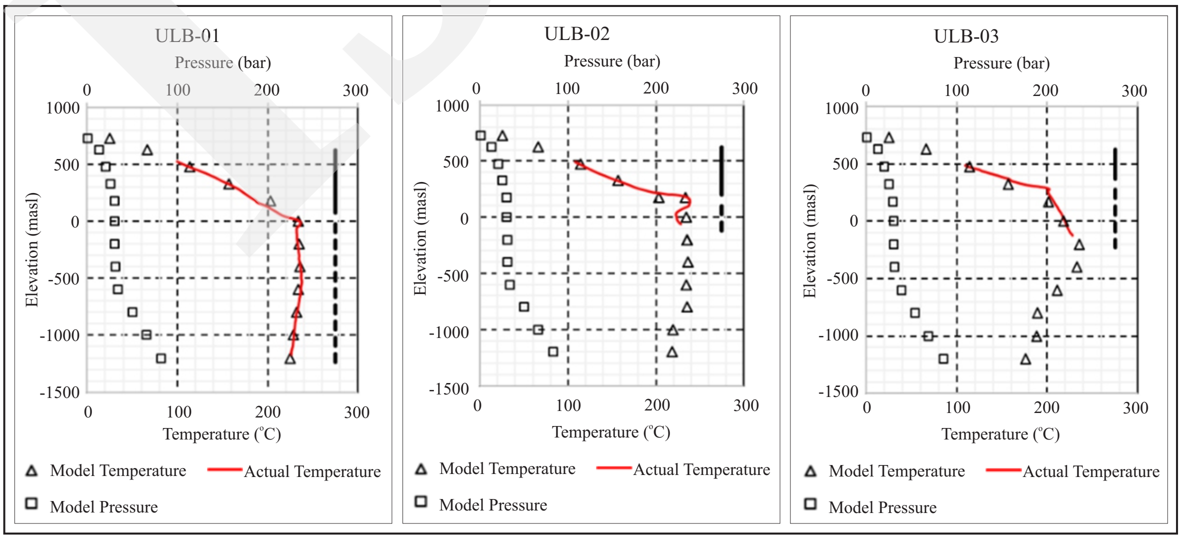

Figure 3. Pressure and temperature matching for ULB-01, ULB-02, and ULB-03 (Kurniawan *et al.*, 2019).

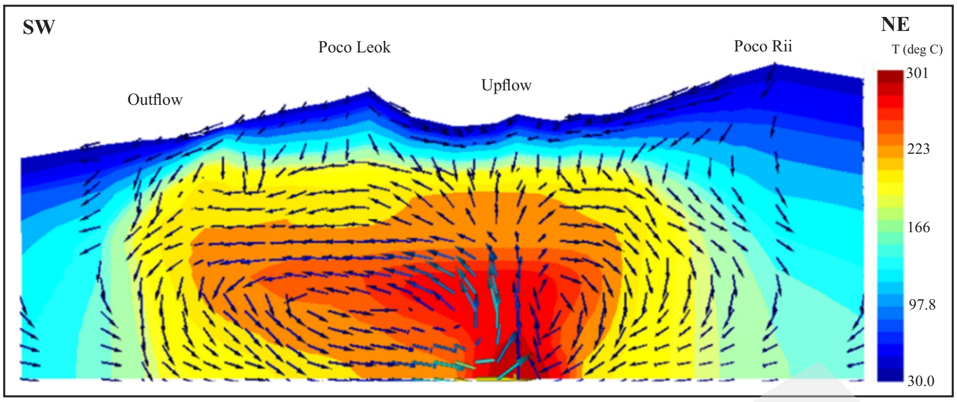

Figure 4. Heat-mass flow in the model agrees with the conceptual model of the Ulumbu field (Kurniawan *et al.*, 2019).

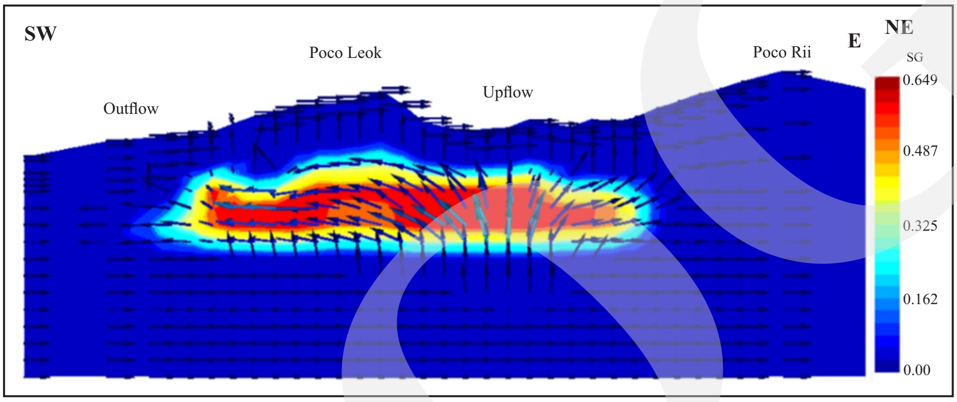

Figure 5. Steam flow at Ulumbu Geothermal Field, the cross-section of gas saturation (Kurniawan *et al.*, 2019).

simulation at the natural state model could be used to update the conceptual model.

The numerical model and heat stored are the most commonly applied methods in geothermal resource assessment. The heat stored method is considered the most practical approach but with uncertainties in the parameter inputs. There is no doubt that the reservoir numerical model is the best approach in estimating geothermal resources. Many researchers combined the natural state model with probabilistic heat stored calculation (Ashat *et al*., 2019b; Hasbi *et al*., 2020; Hidayat *et al*., 2018; Kurniawan *et al*., 2019; Pratama and Saptadji, 2021, 2018; Putra *et al*., 2019). In Indonesia, the numerical model is mandatory to estimate the proven reserve based on SNI 6009 (2017) however, it is unclear how to calculate it. Therefore, this paper offers an approach of combining the output of numerical simulation at natural state model with heat stored method to estimate the Ulumbu geothermal reserves.

The estimated geothermal energy reserves were carried out using Monte Carlo simulation, an essential tool, with a range of values of the various reservoir parameters. This probabilistic approach was applied to evaluating reserves that capture uncertainty. The defining values of a reservoir input parameter, numbers within the distribution range, were selected based on the natural state model and attracted over a thousand iterations for each set of calculations. The heat stored method was carried out using a Monte Carlo simulation with 60,000 random numbers to generate a value of the parameters used in calculations. Generating random numbers in a computer programme is a requirement to using any of the Monte Carlo methods. The Ulumbu geothermal field has a steam zone and deep liquid reservoir. Then, Sarmiento and Steingrímsson (2007, 2013) state that hypothetically, it is wise to calculate the heat component from the deep liquid reservoir and the two phases (vapour-dominated zone) of the reservoir.

The parameters used, shown in Table 1, were derived from the study of geoscience data, drilling wells, and natural state models that had been built. The area was based on high temperature from the numerical model; thickness was based on the numerical model and ULB-01 well. The rock density was based on gravity data and SNI 6482:2018; the porosity was based on the numerical model, and SNI 6482:2018; rock heat capacity was based on Vosteen and Schellschmidt (2003) and SNI. Recovery factor was based on Muffler and Cataldi (1978) and SNI 6482:2018; electric efficiency was based on Bodvarsson (1974). The initial reservoir temperature was based on well temperature; the initial water saturation was based on a numerical model; the final water saturation was based on Ashat *et al.* (2019b). The economic life of the project is 30 years based on SNI 6482 (2018).

Results

The estimation result of the Ulumbu using the heat stored method shows that the cumulative distribution used Monte Carlo simulation (Figure 6) and the probabilistic result of P10-P50-P90 are shown in Table 2. The probabilistic result of P10-P50-P90 in all steam, are 44 MWe, 60 MWe, and 81 MWe, respectively. In contrast with the probabilistic liquid, the reservoir is, consecutively, 27 MWe, 35 MWe, and 46 MWe.

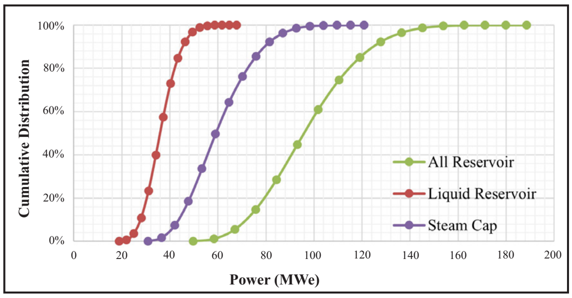

Figure 6. Cumulative probability of heat stored method.

Table 2. Heat Stored Calculation Results for Each Zone

Probability	Power (MWe)		
	Steam Cap	Liquid Reservoir	All Reservoir
P10	44	27	71
P50	60	35	95
P90	81	46	127

The liquid reservoir and steam zone calculation from the Ulumbu field shows that the steam zone is superior to the liquid reservoir. Overall, the reserve of the steam zone is almost double to the liquid reservoir. The probabilistic result of P10-P50-P90 in all steam are 71 MWe, 95 MWe, and 127 MWe, respectively. The calculation result shows that P50 is 95 MWe, close to the ESDM calculation result (2017) of 100 MWe. Because the reservoir area uses resistivity survey data (Magnetotellurics – MT) and The Ulumbu produced 4 x 2.5 MWe, calculated reserves fall into the category of probable reserves. Similar to SNI Standard, the reserve is categorized as probable because of the

Table 1. Input Parameter of Each Zone for Heat Stored Method

Parameters	Vapor			Liquid			Remarks
	Min	Max	Most	Min	Max	Most	
Area (km^2)	19.8	24.2	22	19.8	24.2	22	Model
Thickness (m)	400	1000	600	400	800	600	Model, ULB-01
Rock Density (kg/m^3)	2400	3000	2600	2400	3000	2600	Gravity, SNI
Porosity	0.07	0.1	0.08	0.05	0.08	0.07	Model, SNI
Rock Heat Capacity (kJ/kg)	0.95	1	0.985	0.95	1	0.985	(Vosteen and Schellschmidt, 2003), SNI
Recovery Factor	0.175	0.25	0.213	0.125	0.2	0.175	(Muffler and Cataldi, 1978), SNI
Electric Efficiency	0.11	0.112	0.111	0.105	0.11	0.108	(Bodvarsson, 1974)
Initial Reservoir Temperature (°C)	235	240	237	225	234	230	Well Temperature
Initial Water Saturation	0.3	0.35	0.325	0.65	0.7	0.675	Model
Final Water Saturation		0.05	0	0.3	0.5	0.4	(Ashat *et al.*, 2019b)

areal extent based on MT and indicative that the Ulumbu has high-temperature resources. This area is potential for well-targeting.

The heat stored method calculates the recoverable thermal energy for the specific volume, temperature, and exploitation time of the geothermal reservoir. Through the Monte Carlo simulation, the probabilistic approach of estimating geothermal reserves becomes less demanding. It is generally used and has been proven to be practical in estimating geothermal resources and reserves. The method is useful in estimating potential resources to geothermal prospects during early exploration, where the available data is limited. The total theoretical thermal and electrical powers can be calculated from the thermal energy stored in rock and fluids. However, based on the SNI 6009:2017, the proven reserve should be estimated using numerical simulation. Therefore, in this study, the parameters used for the heat stored method are obtained from reservoir numerical simulations.

The results of sensitivity analysis for the calculation of the steam zone and liquid reservoir are shown in Figure 7. The results showing reservoir

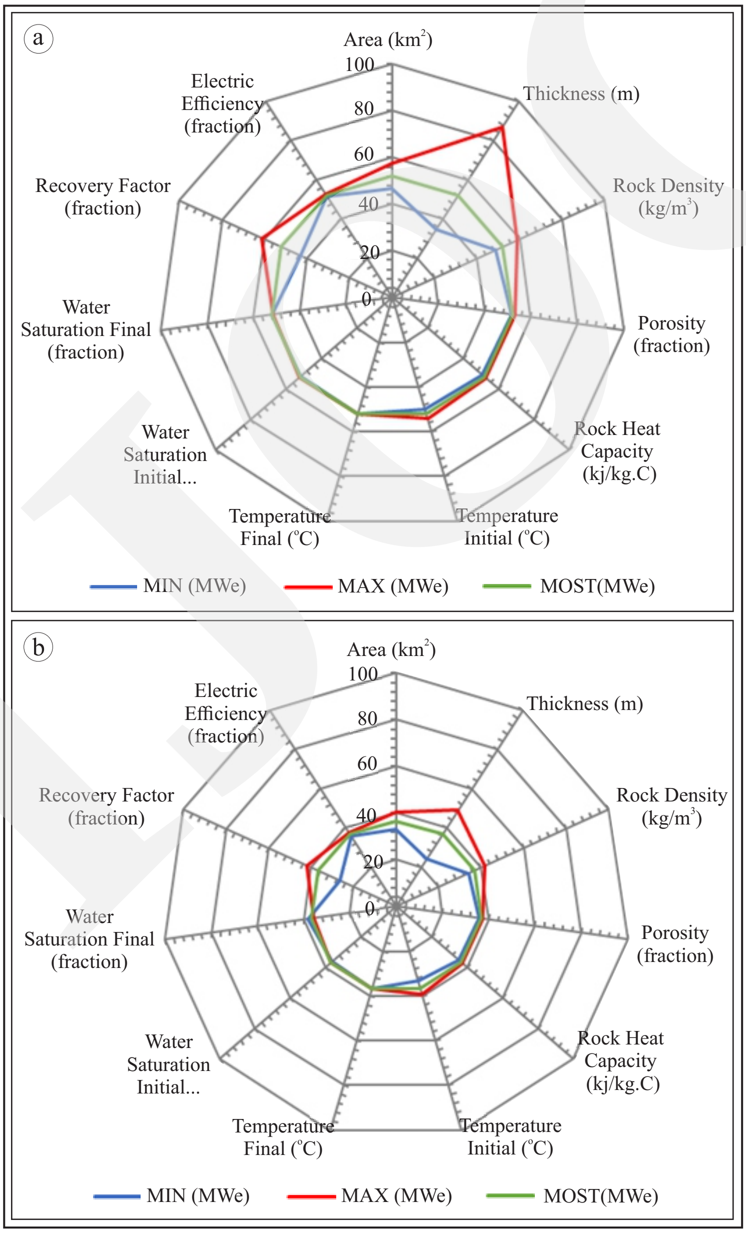

Figure 7. Sensitivity analysis of heat stored method: (a). steam zone and (b). liquid reservoir.

thickness and recovery factors are the most sensitive parameters for the steam zone and liquid reservoirs. Therefore, the determination of these parameters must be done carefully so as not to produce incorrect calculations.

The thickness is the most sensitive parameter in each steam zone and liquid reservoir. The vertical extent of the resource was delineated based on the fluid phase in the reservoir. The range of thickness in the steam zone is around 400 - 600 m contrasts with the liquid reservoir around 400 - 800 m. Nevertheless, both reservoirs have an identical, most likely thickness at 600 m.

Defining the portion of the geothermal energy that is practically recoverable at the wellhead (surface) is challenging. This factor makes the heat stored method be extremely uncertain and inaccurate. The recovery factor is dependent on the permeable reservoir and the heat sweep efficiency from these permeable channels. This parameter depends on the reservoir thermodynamic and hydraulic characteristics, such as reservoir area, temperature, permeability, porosity, and recharge.

Conclusions

The combination of reservoir numerical simulation and heat stored method with Monte Carlo simulation is suitable for estimating a probabilistic geothermal reserve. The geothermal resource assessment of the Ulumbu Geothermal field with a steam zone reservoir underlying liquid reservoir has been estimated using the combined methods. The calculation is divided into the steam zone and liquid reservoir with a total capacity of probabilistic P10-P50-P90, 71 MWe, 95 MWe, and 127 MWe, respectively. However, the critical issue of the heat stored method is an oversimplification of the actual geothermal reservoir. Therefore, to address this issue, the latest geothermal resource assessment methodology method is Experimental Design (ED) and Response Surface Methodology (RSM). Dynamic modelling could be applied to produce the heat and mass flow from the reservoir numerical model. The ED and RSM method coupled with numerical reservoir modeling is a promising hybrid technique that is effective and efficient to be implemented in geothermal resource assessment.

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